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Fredric C. Lynch

FREDRIC C. LYNCH, Major, USAF
Director of Public Affairs

Air Force Institute of Technology (ATC)
Wright-Patterson AFB, OH 45433

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William Lewis Epperson
March 1980
Physiology

The Effect of Physical Conditioning on $+G_z$ Tolerance

Abstract

The influence of physical conditioning on tolerance to a centrifugation profile of alternating 15 second plateaus at 4.5 and 7.0 $+G_z$--called Simulated Aerial Combat Maneuvering (SACM)--was determined using 24 young men as subjects. These subjects were assigned to groups as controls (C) (no physical training), runners (R), and weight trainers (W); and followed a 12 week protocol of specified physical training. During this protocol, tolerance to centrifugation, maximum oxygen consumption, muscle strength, and body composition were periodically determined. Venous blood samples and fatigue assessments were taken before and after the SACM tolerance tests at the beginning and end of the study. SACM tolerance was defined as the total time that a subject could withstand continuous exposure to the centrifugation profile as determined by his voluntary endpoint from fatigue or 50% central light loss. The $+G_z$ tolerance of the runners and controls increased at an average rate of 4 seconds per week during the course of the experiment. On the other hand, the weight trainers increased their G tolerance at an average rate of 15 seconds per week. The differences between group W and groups C and R were statistically significant at the 5% level. Significant correlations were found between both sit up and arm curl training weights and SACM tolerance times; and the exponential relationship was found to give higher correlation coefficients than the rectilinear relationship. No significant relationship was found between plasma volume shift and SACM tolerance time. Fatigue scores indicate that group W subjects take longer to reach a given level of fatigue than did the subjects of the other groups. It appears therefore that a physical conditioning program of weight training will improve human tolerance to repeated and prolonged exposure to high $+G_z$ loads.

The Effect of Physical Conditioning on +Gz Tolerance

By

WILLIAM LEWIS EPPERSON
B.S. (University of Illinois) 1962
M.S. (University of Illinois) 1964

DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

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in the

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of the

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DAVIS

Approved:

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Committee in Charge

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DEDICATION

This thesis is dedicated to Dr. R. E. Johnson--a friend, a teacher, and an inspiration to students; and to aircrews everywhere who must meet and sustain the challenge of the environment of flight.

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A project with the scope of the one reported in this thesis could not be accomplished without the cooperation of the personnel of several organizations. Specifically, I acknowledge the help of the following:

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Drs. Russell Burton, Sidney Leverett, and Pat Iampietro, and Mr. Hubert Tomerlin and many others who's guidance and assistance provided the expertise to accomplish this project.

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INTRODUCTION

In recent years, the "new generation" of high performance fighter aircraft (F-14, F-15, F-16, F-18, and A-10) has generated interest in the ability of the aircrewmember to perform in the maneuvering high-G environment that these aircraft are designed to sustain. Pilots of aircraft flying in the high-G environment appear to suffer from G fatigue and are therefore interested in ways to aleviate this condition (21).

The broad physiologic effects of acceleration are reasonably well understood (18, 29, 31, 32, 45). In dealing with the relaxed individual, the principal physiologic functions and limitations of tolerance to G involve the cardiovascular system.[1/] On the other hand, less is known about the physiologic events and adjustments which occur with high levels of acceleration, and of the physiologic basis of methods used to alter acceleration tolerance.

Individuals can increase their G tolerance above the relaxed level by: (a) using a functioning anti-G suit,[2/] and (b) performing an M-1 straining maneuver.[3/] The M-1 is required above 5 G for most pilots wearing an anti-G suit. Since the M-1 is a very physical activity, it by itself can be extremely fatiguing. Therefore G tolerance is a term which is meaningless unless the tolerance measurement is described as "relaxed" with or without the G-suit, or "straining" with or without the G-suit.

REVIEW OF THE LITERATURE:

The influence of physical fitness and related parameters on both relaxed and straining G-tolerances has been considered by several investigators over the years.

Relaxed G Tolerance:

Population Variability:

Populations or cross sectional differences have been investigated by Cochran *et al.* (24), Hyde *et al.* (38), Stepantsov and Yeremin (62), Suverov (64), Klein *et al.* (42, 44), Whinnery *et al.* (72) and Meehan and Jacobs (49). Cochran *et al.* (24) tested several groups of subjects which include Naval pilots, cadets, referral students and flight medical personnel (total N = 1000) for relaxed tolerance to a G onset of approximately 3 G every 2 sec. He found no significant difference in tolerance to G between the groups tested. He did note large variations in tolerance, but there was no relationship between "physical findings and living habits" and G tolerance.

Hyde *et al.* (38) tested 31 test pilots and 15 non-pilots. Since the pilots were allowed to strain and the non-pilots were "relaxed" no comparison could be made between the groups. However, within the pilot group there was no correlation between 104 variables (not all were specified but included were anthropometric indices and physical fitness tests) and blackout tolerance.

Stepantsov and Yeremin (62) concluded that gymnasts, classical wrestlers, weight lifters, and sprinters have the greatest $+G_x$ tolerance. Tolerance in this plane (front-to-back) is usually limited by respiratory distress (29) and therefore may not be directly relavent to $+G_z$.

Suvorov (64), however, did find significant differences in relaxed acceleration tolerance ($+G_x$ and $+G_z$) among three populations of subjects involved with different types of physical training. Unfortunately the stature of these individuals apparently was not considered during the experiment. The group which was most acceleration tolerant was composed partially of weight lifters who tended to be short in stature and as will be noted subsequently the physical parameter of heart-eye distance relative to stature is inversely related to relaxed G-tolerance (Klein, 42, 44).

Klein _et al_. (42, 44), in studying aerobically trained and non-trained students, noted that acceleration tolerance was inversely dependent on heart-eye distance and directly on systolic blood pressure.

Meehan and Jacobs (49), in their study of bed rest and general exercise training on relaxed G tolerance, considered systolic blood pressure relative to relaxed G tolerance. Although their report is brief and data analysis is incomplete, a direct statistical relationship exists between G tolerance and systolic blood pressure.

Whinnery _et al_. (72) recently evaluated 59 male aircrewmembers undergoing aeromedical evaluation at the USAF School of Aerospace Medicine for ROR and GOR relaxed G tolerances. They correlated several clinical parameters with high and low G tolerance. The subjects having the highest relaxed G tolerances were older, shorter, heavier, and had higher maximum systolic blood pressure during a treadmill test.

Bedrest effect:

Meehan and Jacobs (49), Bernauer _et al_. (10) and Greenleaf _et al_. (33, 34) have studied bed rest and its influence on relaxed G tolerance. Meehan and Jacobs (49) concluded that there was no influence on G tolerance after 30 days of bedrest. They did record significant changes in blood volume between imposed rest and exercise but reported no correlation between these volume changes and G tolerance. More extensive studies on the effects of bedrest on G tolerance conducted by Bernauer et al. (10) and Greenleaf et al. (33, 34) however, concluded that bedrest decreases G tolerance. These studies (10, 33, 34) all noted significant changes in relaxed G tolerance after 14 days bedrest. They also recorded decreases in plasma volume after bedrest and after riding the centrifuge. Bernauer et al. (10) hypothesized that the loss of plasma volume during acceleration exposure might be a factor in reducing G tolerance, therefore the decrease in plasma volume associated with bedrest could have caused the reduced G tolerance.

Physical training:

The influence of general physical or aerobic training on G tolerance was the subject of studies by Klein et al. (42, 43, 44), Meehan and Jacobs (49), and Cooper and Leverett (25). Klein et al. (42, 43, 44) found no differences in the tolerance to GOR of 1 G per 15 sec between aerobically trained and non-trained students. In this study leg tensing was used.

In the Meehan and Jacobs study (49), 30 days bedrest was followed by 30 days of general exercise training. They concluded in their brief report that the change in physical condition of an individual (as measured by Harvard step test score) does not effect G tolerance. The lack of influence on relaxed G tolerance of aerobic (running) training was also noted by Cooper and Leverett (25) who put experienced centrifuge riders through a 14 week running training program, and noted no change in their tolerance to either ROR or GOR.

In one of the studies by Greenleaf et al. (34) it was noted that isometric exercise during bedrest could prevent the decrease in relaxed G tolerance whereas no effect was found with isotonic exercise.

Straining G Tolerance:

Physical Training:

A few studies and some general observations have indicated that straining G tolerance can be improved through physical training.

Wessel in 1950, in a PhD dissertation (71), reported that six and a half weeks of weight training and running exercises resulted in an improvement in tolerance to an exposure of 5 G for a maximum of 30 sec without an anti-G suit. She used visual criteria, ear opacity, and duration of straining G tolerance. Twenty three subjects began the training program yet only 15 subjects finished the study. Unfortunately physical activity outside the study was not controlled although the subjects were mostly physical education majors and varsity athletes. However, it is important to note that this study was the first attempt to systematically examine the influence of physical conditioning on a straining type of high G tolerance. This study included in its design instructions on the training of subjects to strain in order to tolerate the effects of 5 G.

In a review article, Vasil'yev and Kotovskaya (69) discuss "increases in the aviator's tolerance to acceleration" by stating "numerous observations of aviation physicians have convincingly proved that general toughening of the body and special physical training, aimed at improving the circulatory and respiratory regulation mechanisms, strengthening the muscles of the thorax and legs, developing breathing habits from the "abdominal" to the "chest" and conversely, capacity for prolonged tonic stress of individual groups of muscles" will increase G tolerance. Unfortunately supportive data were not offered to substantiate these observations.

Another observation relating G tolerance to physical training was made by Stechni and Kikowicz (61) who selected subjects with low G tolerance to participate in a program of specific exercises. They reported that G tolerance was improved in 70% of the cases. Again, as with the previous referenced Russian study, experimental details are not available.

Summary:

Several factors relative to variabilities inherent in a human population appear to affect relaxed G tolerance. Included in these factors are age, stature (heart-eye distance), resting systolic blood pressure, and possibly body mass. On the other hand, physical training appears to have little affect on relaxed G tolerance except possibly to prevent a reduction in G tolerance which accompanies prolonged bedrest.

Unlike relaxed G tolerance however, straining G tolerance, which relates specifically to fighter pilots, may be improved by physical training. At this time however, it is not clear which training regimens are effective and the amount of training necessary to improve this straining type of G tolerance.

EXPERIMENTAL DESIGN:

In actual flight in high performance aircraft (F-4, F-15, F-16, and A-10), the G load can be prolonged and quite variable (Fig. 1). Therefore, for obvious reasons for pilot application, it is necessary to test for G tolerance in the laboratory using a G profile which simulates the fighter pilot's maneuvering environment.

The present study was designed to impose controlled physical training regimens on average fit young adult subjects; to measure changes in physiologic parameters associated with the training regimens; and to measure the influence of these regimens and associated changes in physiologic function on tolerance to a simulated air combat maneuvering (SACM) environment using the centrifuge located at the USAF School of Aerospace Medicine (USAFSAM), Brooks AFB, Texas.

The basic experimental design was that of a longitudinal study of the effects of two different physical conditioning programs: (a) a dynamic, moderate intensity and moderate duration training program which consisted of a combination of long distance continuous running and short distance interval running and (b) a static, high intensity and low duration training program of circuits of specified weight training exercises.

The G profiles (SACM) used to assess G tolerance consisted of alternating 15 second plateaus of +4.5 and +7 G_z continuing until the subject stopped the SACM because of fatigue (Fig. 2). This profile challenged the subjects with repeated periods of moderately high $+G_z$ (+7 G_z) during which considerable effort was expended to counter the effects of the G load, and periods of "active rest" (+4.5 G_z) which allowed some physiologic recuperation. The duration of time (sec) that a subject, wearing an anti-G suit, tolerated this G profile determined his SACM tolerance. The use of this profile to measure tolerance to G has been examined and related to relaxed G-tolerance, performance during G exposure, and several physiologic parameters (20).

METHODS

SUBJECT SELECTION:

Volunteer subjects were recruited from airmen who had just completed Basic Military Training at Lackland Air Force Base, Texas.[4] Thirty subjects were chosen from this group of volunteers for the study. After the volunteers had passed a Class II Flying Physical Examination, they were given an indoctrination ride on the centrifuge. Details of this ride are found below under the title "Subject G-Training."

For logistical purposes the thirty subjects were divided into three training groups with 10 subjects in each group. Each training group had members from each exercise category. Group II began the program 1 week after Group I and Group III followed Group II also by 1 week. For various medical and personal reasons, the number of subjects to complete the experiment in each exercise category were Controls - 9, Runners - 8, and Weight trainers - 7. Consequently, throughout this report only data were used from those subjects who completed the study. The physical characteristics and specific groupings of the individual subjects are shown in Table I.

SUBJECT G-TRAINING:

Five weeks were devoted to training the subjects to tolerate the SACM type of G exposure to their maximum capability and to familiarize them with the treadmill and all other experimental procedures. During this time period, each subject was given six training exposures on the centrifuge. The various G profiles used in this training period are shown in Table II.

On each subject's first centrifuge exposure (indoctrination run), no anti-G suit was worn. The subjects were instructed to relax as much as possible and to look at the center red light of the light bar positioned 30 in. in front and slightly above the level of the eyes (Fig. 3). A hand brake held by the subject was released when the subject judged a loss of 50% or more of the intensity of the peripheral green lights (50% PLL). Later G exposure limits were judged using the more usual 100% PLL and 50% CLL.[1/] This first exposure with a slow G onset (GOR) to 50% PLL permitted a progressive moderate visual loss thus permitting the subject to experience (in a safe manner) the light loss phenomenon. ROR indoctrination runs to a predetermined "safe" G-time plateau exposed the subject to the feel of rapid G onset.

The first and second training exposures (second and third centrifuge exposures) were conducted with the subject wearing an anti-G suit[2/] which was inflated (pressurized) as indicated in Table II. The GOR was similar to the GOR of indoctrination run except the subject used 100% PLL and 50% CLL. The first ROR was 4.5 G for 30 sec with anti-G suit inflated and performing the M-1 for practice. The additional ROR exposure was used to practice the SACM--initially using 6 G plateaus instead of 7 G for some subjects. These early ACM training exposures were terminated after two 6 or 7 G peaks; i.e., were not continued to voluntary fatigue or criteria endpoint.

After the third G exposure (training exposure 3, 4, 5, and 6), centrifuge training sessions followed the same format as the data collection sessions--a ROR to 3 G with a 30 sec plateau (for warm up and equipment check out), then a 4.5 and 7 G profile (Fig. 2) to the end point of fatigue. The acceleration indoctrination and training program is shown in Table II.

In addition to the above orientation regimen, during the five week training period all subjects were instructed not to engage in regular strenuous physical activity. At the end of the centrifuge training period the subjects were divided into the experimental/training categories of Controls (no exercise; C), Runners (R), and Weight Trainers (W). Each training category was balanced for SACM tolerances, physical fitness, and physical characteristics. An attempt was made to evenly distribute in each temporal group representatives from each training category (Table I).

SUBJECT TRAINING FOR PHYSICAL CONDITIONING:

Running Endurance Training:

The running training program was intended to significantly improve the subject's tolerance to moderately intense, long duration work as measured by maximum aerobic capacity ($\dot{V}_{O_2}$ max). The training program included two out-of-doors workouts each day; one in the morning, devoted to continuous running up to 6 miles, and the other, after lunch, was used for paced interval running. The environmental temperature for the runners ranged from a low of 19°C in the morning at the beginning of the study (April) to a high of 36°C in the afternoon at the end of the study (July). At no time was the runner's training interrupted because of elevated ambient temperatures. The weekly goals for this program are shown in Table III. A combination of continuous running over a measured course and paced intervals (on a 440 yd track) was used, either of which can effectively enhance $\dot{V}_{O_2}$ max (65).

The schedule for interval training used in this study is shown in Table V, and is developed from information available from Fox and

Mathews (28) and Adams (1). Their data were displayed on a log scale graph (Figure 4) and from this graph was developed the interval running pace schedule shown in Table IV.

During inclemant weather or for specific subject problems such as shin splints, training sessions were performed on the treadmill or on a Collins electrically braked bicycle ergometer (70). For training on the bicycle ergometer, the subjects were instructed to ride 10 minutes for each mile of the continuous run schedule. This was accomplished at a pedal RPM of 50 to 60, and at a load which would give a heart rate greater than 160 (usually 100 or 110 watts). For interval approximations, the instructions were to use an increased load (200 to 250 watts for short intervals) and a pedal RPM of 90 to 120 for the specified interval time. In all cases, load could be adjusted to allow completion of each set.

Weight Training:

The weight trainers worked out in a ventilated gymnasium once each day in the morning. Although the gymnasium was not airconditioned, the ambient temperature in the morning during their workouts for the entire study never exceeded 27°C. The equipment used for weight training included a Universal Gym,[5/] wall mounted pulley weights, dumb-bells, barbells, benches, and boards.

Two circuits of common exercises (36, 51, 56) were specified for training (Table VI). Each circuit was used every other day so that a two day cycle would exercise all major muscle groups (51). To complete a circuit each exercise was performed for three sets (5, 9) with a 3 min rest between sets.

During the first training session, the 1 rep maximum (1RM) weight was determined for each of the lifting motions. During the second training session, set one was for 10 reps using 70% of the 1RM weight. Sets 2 and 3 used 80% of the 1RM weight with a limit of 10 reps in each set. The weight remained constant until the subject could complete 10 reps on the third set. When this occurred, the subject would add 5 pounds to the "80%" weight for upper body motions, and 10 pounds for lower body motions for the next training session. Appropriate amounts were added to the "70%" weight to maintain its relative level. These weights would be used until the subject once again could complete 10 reps on the third set. This regimen continued for the entire training program.

Two weight lifting exercises differed from the others in their training application. The wrist roller was used only for one repetition (not 10 repetitions) for each set; the weight used on the head strap was only 50% of 1RM--a precaution to avoid neck injury.

For the sit up, a level board was used with the weight held either behind the neck or on the chest.

Controls (no exercise):

The control subjects were not permitted to participate in any kind of regular physical activity or training program. They were assigned as training monitors and record keepers for the physical conditioning programs. In this capacity they were exposed to the same environmental conditions as the subjects in the exercise groups.

Environmental and Living Conditions:

During each running training session values for dry bulb, wet bulb, and black globe temperatures were recorded, and from these the WBGT index was calculated to determine if running training activities should be restricted. As noted earlier, restriction of training activities for either group because of high environmental temperatures was not necessary. In addition, all runners and weight trainers recorded their body weight before and after each training session so as to maintain proper hydration during each day's activities.

All subjects shared the same living accomodations in non-airconditioned barracks at Lackland AFB, Texas, and were bussed to and from Brooks AFB, Texas each duty day. Throughout the study the subjects' off duty time was not controlled except for minor specific restrictions regarding food, drink and sleep the night before and the day of data collection.

MEASUREMENTS OF PHYSICAL FITNESS:

Aerobic Capacity:

Maximum oxygen consumption ($\dot{V}_{O_2}$ max) was determined on all subjects at weeks 1, 4, 8, and 12 of the study. This determination was made on a motor driven treadmill (Fig. 5) using a multistage - branching treadmill test (Table VII). Each walk began with the treadmill speed at 3.2 mph at zero slope (branch II stage 3). The test progressed at two minute intervals through each stage until the subject reached exhaustion and stepped off the treadmill. At each branch point step, heart rate was checked, and if it was below 140 beats per minute (70% of predicted maximum for the age group) the test moved to the next more strenuous branch. If the heart rate was 140 beats or more at the branch point the test remained in that branch for the remainder of the walk. With this procedure most tests were completed in 16 to 20 minutes of walking.

Physiologic measurements were taken continuously during the treadmill test, from two minutes pre-walk (subject standing) through a two minute post-walk recovery (Fig. 6). Expired air composition was determined by a Perkin-Elmer Model 1100 Medical Gas analyzer. Percentages of O_2 and CO_2 were recorded in tabular form every 15 seconds during the test. In addition, expired gas volume (from the output of a Parkinson-Cowen gasometer), O_2 and CO_2 percentages (from the Medical Gas Analyzer), and heart rate (from a cardiotachometer) were recorded on a strip chart (Brush 440 Recorder). Treadmill speed and elevation; and inlet and outlet temperatures of the gasometer, as measured by Telethermometer, were all annotated on the strip chart at regular intervals. An example of the strip chart excluding the CO_2 channel is shown in Fig. 7. The $\dot{V}_{O_2}$ max was used to evaluate aerobic fitness of all of the subjects engaged in the study.

Total blood volume was determined for all subjects by a trained technician during weeks 1, 8, and 12 using CO rebreathing techniques (52). Since it is well established that blood volume increases with running training (37, 54) and hot climatic conditions (48, 60), changes in blood volume during the training program also were used to estimate aerobic conditioning.

During the entire running program, each subject recorded all distances run and the times to complete each distance for each training session. From these records, the total miles trained on a weekly basis also became useful as an indicator of aerobic capacity.

Muscular Strength:

Muscular strength of the weight trainers were determined by recording the training weight for four major exercising muscle groups (arms, chest, abdomen, and legs). These weight lifting motions were the arm curl, bench press, sit up, and leg press respectively. These muscle groups are representative of the major muscular functions which would appear to be most useful in performing the M-1. During the first week of the study, the 1RM weight for these motions identified the initial training weight for each muscle group. To quantify muscular strength, throughout the study, the "80%" training weight value was most useful.

Weight training effects for specific muscle masses were also determined by periodically measuring the following body circumferences: chest, abdomen, dominant flexed biceps, and dominant thigh. These were measured on weeks 1, 4, 8, and 12 of the study by an experienced technician.[6]

General Physical Fitness:

Changes in body size and composition over the duration of the study were determined for all groups by periodic measurements of body mass, % body fat, and height. Body fat was calculated from water displacement values using a whole body volumemeter (3) and from radioisotope (^{40}K) methods using the USAFSAM whole body counter (57, 66).

G-TOLERANCE QUANTIFICATION:

Acceleration tolerance was determined using the USAFSAM School centrifuge (Fig. 8) (39). This centrifuge has a 6.1 m radius, is hydraulically driven, and has a 1 to 2 G per sec onset rate maximum capability. The gondola on the centrifuge used for human exposure, orients during G so that the seated subject (13° back tilt) is exposed to a $+G_z$ force.

Prior to exposure to acceleration, each subject was instrumented with 2 sets of electrocardiogram (ECG) leads--sternal and biaxillary--for heart rhythm and rate. The subject was also fitted with an anti-G suit (USAF CSU-12/P) and a restraint harness (Fig. 9).

The subject was then positioned in an aircraft seat (13° seatback angle) in the gondola of the centrifuge. An ear oximeter was placed on his right ear to monitor arterial oxygen saturation (Fig. 10).

Consequently during G exposure the subject was monitored using two ECG channels, an ear oximeter for continuous measurement of arterial saturation (11), closed circuit television (Fig. 11), and two way audio communication. A medical monitor and a central observer in the control room observed the subject at all times during a centrifuge run. They could stop the run any time at their option. A specific medical criterion used for stopping a run was: arterial blood saturation less than 60% [as measured by Hewlett Packard ear oximeter model 47201A (11)]; or a heart rate over 200; or paired premature ventricular heart beats; or frequent abnormal heart beats judged by the medical monitor to be potentially dangerous.

Before the SACM tolerance run to fatigue was made, the subject was exposed to 30 sec of 3G to check out the medical monitoring equipment, and anti-G suit inflation, and to stimulate his cardiovascular system. It is well known that the relaxed G-tolerance of an individual is higher for his second G exposure than for his first centrifuge exposure of the day.

As noted earlier, the SACM test consisted of alternating 15 sec plateaus of 4.5 and 7.0 G (Fig. 2). Exposure to the test profile was continuous until each subject's voluntary endpoint of fatigue was reached. Upon reaching his point of fatigue, the subject stopped the centrifuge by releasing the positive acting brake held in his left hand (Fig. 10). During G exposure each subject wore a functioning anti-G suit and performed the M-1 straining maneuver as necessary to maintain visual criteria; and monitored the light bar. If during any centrifuge run, 100% of the peripheral lights and/or 50% of the central light intensities were lost, the subject stopped the centrifuge.

A G-tolerance measurement was not considered acceptable if the acceleration run was stopped for reasons other than fatigue. A subject's tolerance time was defined as the time spent continuously at a G load greater than 2 G. Tolerance to the SACM profile was measured on weeks 1, 3, 4, 6, 8, 10, and 12 of the protocol.

At week 11, each subject was exposed to the SACM profile for a duration equal to their SACM tolerance time determined in week 1 (baseline). This allowed for data, derived from a similar SACM exposure time, to be compared between physically trained and untrained subjects.

On weeks 1, 11, and 12, blood samples (10 ml each) were taken by either venipuncture or indwelling venous catheter (subject's choice) from a superficial vein in the forearm. These samples were taken immediately before and after the SACM with an additional sample drawn 20 minutes following exposure to the SACM. These blood samples were analyzed for hematocrit and lactate (22). Plasma volume changes during the SACM were determined from these venous hematocrits using methods described elsewhere (68).

The fatigue status of each subject relative to an SACM exposure was subjectively determined using the fatigue score list shown in Fig. 12 (35). A fatigue score was determined for each subject immediately before and after the SACM and 20 min after the SACM using the fatigue score list. Each subject checked each of the 10 items once (better than, same as, or worse than) as how he felt at that time relative to each item statement. A fatigue score was developed from the sum of points from the 10 items. Each item was scored as follows: (a) better than = 2 points, (b) same as = 1 point, and (c) worse than = 0 point. Consequently, a low fatigue score indicated a high fatigue status; e.g., a subject that was quite fresh (without fatigue) had a fatigue score near 20. A comparison of fatigue scores between those immediately before with those immediately after estimated the amount of fatigue caused by the SACM exposure. The fatigue score determined 20 minutes after the end of the SACM exposure measured the degree of recovery from the SACM fatigue.

RESULTS

PHYSICAL CONDITIONING:

Since the object of this study was to determine the total 12 week effect of two different physical training programs, the data for weeks 1 and 12 of the study were compared. The first week served as the baseline condition and the last week of the study measured their final physical condition. If significant differences existed regarding the effects of the physical conditioning program, then these would be most apparent comparing the parameters of the individuals at the beginning of the study with those measured at the end of the study when the greatest effect of training had occurred. These data were statistically compared by paired t-testing and summarized as group means ±SE in Table VIII.

Two of the subject groups participated in vigorous training programs specifically designed to develop strength or endurance. Therefore one would expect there to be different physiological and physical changes recorded for the different subject groups. The analysis of these changes is important in order to verify their participation in the training programs and to relate to any alteration in SACM tolerance time.

Body Mass and Composition:

Over the three month physical conditioning period the weight trainers increased their body mass by 1.6 kg, whereas neither the controls nor the runners recorded a significant change in body mass. This body mass change in the weight trainers was consistent during the course of the study (weeks 1, 4, 8, 12) which resulted in a significant correlation coefficient ($p < 0.01$) and the following regression:

$$BM = 69.6 + 0.159t \quad \text{. . . . . (1)}$$

where:

BM = body mass (kg)
t = time in weeks.

Equation (1) suggests that the weight trainers gained about 160 grams of body mass per week during the experiment. In addition to this body mass gain, the weight trainers lost about 2 kg of fat (volume method) per subject for a net increase of lean mass of about 3.6 kg. Such an increase in lean mass clearly demonstrates the muscle hypertrophic effects of the weight training program.

By contrast, the running group replaced about 2.5 kg of fat with lean mass—a shift which reflects the high caloric expenditure of the long distance run and muscle building strenuousness of the interval training. The control group did not change body mass but did lose about 1.5 kg of fat. Since the average age for all subjects was about 19 years, it is likely that many subjects were still growing; i.e., an average increase in height of 4mm for each of the subjects was measured over the course of the study.

In measuring the % body fat, the body volume method was utilized in these results. Interestingly, the ^{40}K whole body count method consistently measured less fat than the volume method (Table VIII). This was especially evident for the weight training group. The reason for this systematic difference between scientifically acceptable methods is not clear.

The changes in % fat (volume method) during the course of this study appeared to occur consistently for all three groups. Correlation coefficient and regression analysis for % fat at weeks 1, 4, 8, and 12 for the 3 groups are shown in Table X. As found for the groups in Table VIII, the greatest and most rapid loss of fat (approximately 217 gm per week) occurred in the runners whereas, the rates of fat loss in the controls (138 gm per week) and weight trainers (179 gm per week) were considerably slower.

The specific training effects relative to changes in body conformation for the three groups are shown in Table IX. The same types of statistical comparisons were made here as in Table VIII. For the weight trainers, the respective 4.2% and 3.1 % increases in chest and flexed biceps circumferences indicate that the muscles of the thorax and upper arm increased in size. Although no significant changes were seen in the abdomen and thigh, the loss of abdominal and muscle fat would attenuate any circumference change resulting from an increase in lean mass.

Those alterations for group W are put in perspective when they are compared to the conformation data for groups C and R. Group C, as expected, did not show any significant conformation change. Group R, however, recorded a 1.9% mean decrease in flexed bicep circumference and a 1.8% mean decrease in thigh circumference. These circumferences changes suggest the reduction in subcutaneous fat associated with the increase in daily metabolic expenditure. The approximate 1% decreases in chest and abdomen circumferences for the runners, although showing the same trend as the biceps and thigh circumferences, which suggests similar conformation changes, were not significant at $P < 0.05$.

<u>Muscular Strength</u>:

Strength measurements were considered for four major lifting motions because these corresponded to the major muscle (body) groups described Additionally, these 4 lifting motions are direct and fundamental commonly weight training efforts. These measurements were determined only for the weight trainers and are shown in Table IX.

The weight training group were of average strength for their age when the program began. Their week 1 1RM bench press averaged 125 pounds, which is similar to the initial strength published elsewhere for 177 college freshman (5).

The increase in muscle strength was statistically significant (paired t-test) for all four motions. These increases in strength ranged from 26% for the bench press and arm curl to nearly 100% for the sit up.

The changes in strength for the weight trainers for the sit up and arm curl were consistent during the course of the study (weeks 1, 4, 8, and 12), thus resulting in significant correlation coefficients ($P < 0.01$) and the following regressions:

$$S = 30.4 + 3.32\ t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$A = 61.6 + 1.74\ t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where:

S = sit up weights (lbs);
A = arm curl weights (lbs); and,
t = time in weeks.

Although the initial weight for the sit up (30.4, eq. 2) was approximately 50% those of the arm curl (61.6, eq. 3), the increase in strength (lbs per week) was twice as great for the sit up (3.32 lbs/week) as for the arm curl (1.74 lbs/week). Consequently, at the end of the study, the final weights being used for each motion were quite similar; i.e., 60.9 lbs for sit ups and 75.7 lb for the arm curl (Table IX). Since the trained strength capacity of the biceps and abdominal muscles are quantitatively similar, yet the untrained strength of the biceps is twice that of the abdominals, it appears that the abdominal muscles are probably used much less on a routine daily basis.

Since the muscle strength for the abdominals increased so rapidly during the study, the weights used in the sit up motion per individual subject was followed on a weekly basis (Fig. 13). Unexpectedly, the weight trainers develop into two groups, relative to muscle strength of abdominal muscles after week 5 of the training schedule. At this time, three of the seven subjects rapidly increased their abdominal strength which then appeared to plateau during the last 3 weeks of the study. The stronger group was training with approximately 80 lbs (80% 1RM) whereas the other weaker group used 50% less training weight.

To ascertain if there was any relationship between muscle circumference and muscle strength within the weight training group, correlation coefficients were calculated for body circumference vs. muscle strength--chest and flexed biceps circumferences against bench press and arm curl training weights respectively. Of these statistical comparisons, the only significant correlation ($P < 0.05$) was with biceps circumference and arm curl weight which resulted in the following regression equation:

$$B = 27.8 + 0.065A \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

where:

B = flexed biceps in cm; and,
A = same as eq. 3.

The arm curl motion is a relatively simple motion involving the contraction of three primary muscle flexors. Therefore it appears that the size of the flexed bicep muscle group has a high correlation with its strength, as measured with the weight being lifted in the curl motion.

Aerobic Capacity:

The degree of aerobic fitness, as measured by $\dot{V}_{O_2}$ max, of each subject was determined four times during the study--weeks 1, 4, 8, and 12. These results presented in Table VIII indicate that the running group increased their aerobic fitness by 7.5% as a result of the running training whereas groups C and W recorded nonsignificant decreases in $\dot{V}_{O_2}$ max. The changes in $\dot{V}_{O_2}$ max are within the expected range considering the type of training programs engaged in by each of the experimental groups.

The initial $\dot{V}_{O_2}$ max for an individual subject had a range of 42.2 to 55.1 ml per min per kg body mass which indicates that all of the subjects were in average to above average aerobic condition (4, 40). Since our subjects had recently completed USAF Basic Military Training, their good condition is not surprising. At the end of this study (week 12) the range in $\dot{V}_{O_2}$ max for the individual runner was 47.7 to 58.4 ml per min per kg body mass which indicates the excellent aerobic physical condition of this trained running group.

The $\dot{V}_{O_2}$ max changes with time for the entire study were calculated using correlation coefficients and regression analyses for the 3 training groups using data from weeks 1, 4, 8, and 12 (Table X). Although a statistical increase in $\dot{V}_{O_2}$ max occurred only in group R (paired t-test; first week compared with week 12, Table VIII), all 3 exercise groups had significant correlation coefficients with time.

Groups R had an increase in $\dot{V}_{O_2}$ max by an average of nearly 1% per week whereas groups C and W recorded slight yet consistant decreases. Groups C and W were probably deconditioning from the aerobic fitness levels achieved in Basic Military Training--the type of physical activity engaged in by group W was not adequate to prevent some aerobic deconditioning.

For group R, the greater rate of change of $\dot{V}_{O_2}$ max as determined by regression (1% per week) over that indicated by comparing pre and post values (Table VIII) results from the direct close relationship of $\dot{V}_{O_2}$ max with the intensity of training. Figure 14 presents the total miles run each week by each subject in group R. Generally, the mileage run increases each week through week 9 then decreases during the last 3 weeks. Likewise the average $\dot{V}_{O_2}$ max increased from week 1 through week 8 and then decreased at the week 12 determination (week 8 = 54.0, week 12 = 52.9 ml per min per kg body mass).

Blood Volumes:

Another indication of the effects of the training programs is reflected in the changes in blood volume shown in Tables VIII and X. Only the runners had a significant increase (paired t-test) in blood volume during the course of the study. Group R recorded a 7.5% increase between the pre and post training measurements (Table VIII) and about a 1% increase in blood volume per week using regression analysis (Table X). Blood volume changes were qualitatively similar to those of $\dot{V}_{O_2}$ max relative to the intensity of training. The weekly blood volume change from week 1 to week 8 was 60 ml per week while there was a smaller weekly increase of 27 ml per week from week 8 to week 12. This increase in blood volume in the runners was to be expected for subjects engaged in an aerobic conditioning program (4, 37, 54).

Interestingly, the weight trainers recorded a nonsignificant yet substantial increase in blood volume that was not entirely unexpected--group W had an individual subject average increase of about 400 ml (6.9%) in blood volume during the 12 week study (Table VIII). An increase in blood volume associated with weight training has been reported previously but the exact relationship is not completely clear at this time (personal communication, Dr. E. M. Bernauer, Univ. of Calif. at Davis). Three conditions in our study could possibly have contributed to the change in blood volume for the weight trainers, 1) the weight training program per se; 2) aerobic deconditioning (4, 50); and, 3) an increase in environmental temperature during the course of the study (48, 60) (average daily maximum and minimum centigrade temperatures were respectively 23.3° and 15.0° for mid-April; and 33.9° and 22.8° near the end of June).

Group C did not have a change in blood volume. However this group was also exposed to two conditions similar to the weight trainers which have been proposed as possibly contributing to the change in blood volume in Group W, namely aerobic deconditioning and an increase in environmental temperature. Therefore weight training appears to be a critical factor in the increase in blood volumes of the subjects in group W.

<u>Summary</u>:

In summary, the results of physical conditioning verify that each training group (C, R, or W) responded as expected relative to its kind of training program. The control group remained essentially unchanged for all parameters with the exception of a slight loss of body fat and minor aerobic deconditioning. The runners became aerobically conditioned as indicated with a net loss of body fat reflected by a decrease in biceps and thigh circumferences, a significant increase in $\dot{V}_{O_2}$ max, and a significant increase in blood volume. The weight trainers gained body mass with increases in lean body mass and a loss of body fat. The weight trainers also became significantly stronger with increases in chest and biceps circumferences. In addition, an increase in blood volume (although not statistically significant) occurred in this group.

It appears therefore, that the two conditioning programs for the runners and weight lifters were of sufficient intensity and duration to statistically change the physical and physiological statuses of the members of the three groups. Consequently, the members of one experimental group, including the controls, were significantly different from the members of the other groups relative to physical conditioning. Therefore, changes in SACM tolerances, as measured in this study, if significantly correlated with an experimental group, can be attributed to that specific physical conditioning program.

G TOLERANCE:

All subjects had their SACM tolerance times determined on weeks 1, 3, 4, 6, 8, 10 and 12 of this study. As with the physical training parameters, these SACM tolerances data were statistically analysed using paired t-testing between week 1 and week 12. These SACM tolerance evaluations are presented in Table VIII. A significant increase (paired t-test) in tolerance times for the weight trainers was found. The SACM tolerance increases for groups C and R were small (about a 25% increase) and were not statistically significant. These small increases in tolerance times for groups C and R suggest that repeated exposure to SACM over several weeks time may provide a learning experience. For all groups there was no evidence of any plateauing of tolerance times near the end of the experiment. A statistical comparison (student's t-test) of SACM tolerance means for week 1 between groups C, R, and W found no significant differences. However, at week 12, group W had a significantly higher tolerance time mean than groups C and R ($P < 0.05$).

The rate of change of G tolerances for each experimental group was determined using correlation coefficients and regression analyses for weeks 1, 3, 4, 6, 8, 10, and 12 (Table X). Regression analysis for group W indicated that the weight trainers increased their SACM tolerance time by over 15 seconds per week. By contrast, groups C and R indicated a significant increase in tolerance time of just over 4 seconds per week. As suggested earlier, tolerance time changes demonstrated by groups C and R suggest a learning effect--probably indicating that the subjects improved their M-1 skills during the course of the study. A statistical comparison of the average tolerance time slopes of each group found that group W had a significantly greater rate of SACM tolerance time increase than either the controls or the runners ($P < 0.05$).

The large increases in SACM tolerance times of group W suggests that weight training can significantly increase a subject's ability to withstand the SACM environment. Therefore further data analyses focused on the changes in group W with respect to the training program and SACM tolerance.

In order to determine the importance of the four selected weight training motions (bench press, sit up, arm curl and leg press) in the improvement of SACM tolerance, tolerance time was statistically compared by regression analysis to the 80% training weights for the first and last (designated week 1 and week 12) training weeks combined (Table XI).

Of the four motions, significant correlations were found for SACM tolerance times with sit up and arm curl weights--sit up giving the highest correlation coefficient (r and r^2 values for the four motions were 1) sit up: $r = .733$, $r^2 = .537$; 2) arm curl: $r = .663$, $r^2 = .440$; 3) leg press; $r = .438$, $r^2 = .192$; 4) bench press: $r = .400$, $r^2 = .160$; all for 14 pairs each). These analyses indicate that abdominal strength (sit up) and upper arm strength (arm curl) are most important in determining ability to tolerate the SACM with the single most important factor being abdominal strength (Figs. 15 and 16).

The coefficients of determination (r^2) specify that about 54% and 44% of the SACM tolerance times can be accounted for by abdominal strength and arm strength respectively whereas the leg press and bench press each will determine less than 20% of SACM tolerance. However, the combined influence of all of the training motions as determined statistically through multiple regression ($r = 0.78$; $r^2 = 0.61$) indicate the importance of total body muscle strength in determining SACM tolerance (Table XI).

As noted earlier, group W subjects separated into two subgroups with respect to sit up training weights (Fig. 13). The subgroups were compared for differences in their SACM tolerances--the three subjects with the sit up training weight of approximately 80 pounds had a SACM tolerance mean of 522 sec, whereas the weaker group had a SACM tolerance mean of 329 sec (37% less than the stronger sit up group).

The exponential relationship of SACM tolerance with weight training strength was also determined using the data from the first and last training weeks (Table XI). Ln G was significantly correlated with sit up and arm curl training weights--these correlation coefficients with sit up and arm curl were higher than the rectilinear relationship between SACM tolerance times and the same training weights.

Although the correlation coefficients for SACM tolerance with both sit up and arm curl weights are increased, the value for arm curl is considerably enhanced indicating that for the exponential relationship, biceps strength may be the major factor in SACM tolerance. Again bench press and leg press training appear to be minor contributors to SACM tolerance. These larger correlation coefficients using exponential functions for each motion suggests that tolerance times rise exponentially with an increase in muscle strength. Such a phenomenon could be expected since the function of workload duration and percentage of maximum possible workload utilized, exhibits a similar relationship to that of Ln G and training weight (4).

As with the rectilinear function between SACM tolerance and training weight, multiple regression demonstrates that SACM tolerance is a function of total body muscle strength--the correlation coefficient increased to 0.86 and the coefficient of determination increase from a 60% value for arm curl weight only, to 75% for all four motions combined (Table XI).

Further analyses were performed on the sit up and arm curl data relative to SACM tolerance times over the complete weight training program. Correlations of SACM tolerance times with sit up and arm curl training weights were determined for weeks 1, 4, 8, and 12 (Table XI). In general, these correlation coefficients are statistically significant ($P < 0.05$). A statistical significance is found in the data from week 1 for the exponential relationship of both muscle groups and it begins with week 4 for the rectilinear functions. Thereafter, except for week 8 of the sit up data, significant correlations are found between muscular strength and G tolerance. Generally, except for weeks 1 and 8 of the sit up, the correlation coefficients for the exponential relationship are higher than those using rectilinear analyses. That SACM tolerance is strongly influenced by gross biceps and abdominal strength and not by net change in muscular strength is suggested by these statistical analyses—significant correlations occurring after only 4 weeks of weight training when the training weights had not yet significantly increased—sit ups were using 35 lbs and arm curls were training with 67 lbs (note Table IX for initial training weights).

In addition, a change in SACM tolerance as the result of a change in muscle strength was considered using statistical analyses on the changes in SACM tolerance times with the increases in the training weights for the four selected motions. No significant correlations were determined between change in SACM tolerance time and change in any of the training weights.

The average fatigue scores for each experimental group for weeks 1, 11, and 12 are presented for comparison in Table XII. The immediate post G fatigue scores were significantly lower ($P < .05$) than the pre G scores except for group W, week 11. Each group's fatigue scores for pre, post 1 and post 2 for weeks 1, 11, and 12 were also statistically analyzed (analysis of variance). Group W post 1 data were significantly different when these data (post 1 of weeks 1, 11 and 12) were compared by pairing t-testing—group W was not as fatigued after the week 11 G-exposure as they were after the week 1 exposure of the same duration SACM.

To assess the severity of the work performed by the subjects during the SACM exposure, the concentration of lactic acid in venous blood was determined pre G, immediately post G and 20 min post G. The group averages of this data are presented in Table XIII. The mean values for post 1 indicate the SACM environment does not impose a severe anaerobic load on the body (4). The post G lactate levels is similar to those reported previously in other SACM fatiguing exposures (15). These levels of lactate are indicative of a moderate level of aerobic metabolism.

Interestingly the post G lactate concentrations for all groups did not significantly change between weeks 1, 11 and 12. Although group R members had an increased ability to do aerobic work, as measured by $\dot{V}_{O_2}$ max, they did not have significantly different lactate concentrations between weeks 1 and 12, even though they reached fatigue during both SACM exposures. Twenty minutes after the SACM exposure, lactate levels were significantly reduced over levels found immediately post G. This rate of recovery after G is also similar to previously reported data (15).

The changes in plasma volume resulting from SACM exposures for week 1, 11, and 12 for the three experimental groups are found in Table XIII. Plasma volume losses of 13 to 18% during sustained SACM exposures are similar to those reported for SACMs with 10 G peaks, repeated until the subjects were fatigued (15).

DISCUSSION

The present study was designed to determine if a program of a specific type of physical conditioning could improve a pilot's ability to tolerate the acceleration ($+G_z$) stress associated with the air combat maneuvering (ACM) environment. To this end, two physiologically and physically different training programs were studied to determine their importance in altering ACM tolerance.

The flight environment of today's fighter pilot contains numerous physical and psychological stressors which he must tolerate in order to function at a satisfactory flying efficiency. While in the cockpit of a fighter aircraft, the pilot may be subjected to extremes of heat or cold, high pressure altitudes, high background noise levels, restrictive flight gear, reduced visibility, breathing restriction and dehydration. These conditions can persist for up to several hours over a single mission or can reoccur on two or three shorter missions in a single day. While experiencing these stressors, the pilot is required to constantly monitor his aircraft's flight conditions and his three dimensional situation using vision, communication and electronic sensors. At all times during flight the pilot constantly evaluates all incoming information, makes immediate decisions and takes actions on which his life depends. In the combat environment, the monitoring and decision making process is greatly accelerated because of the addition of rapidly changing high threat situations.

A significant portion of this combat environment involves high G maneuvering necessary to avoid or attack any potential threat. Consequently, acceleration forces add a significant physical and physiological stress to the pilots total work load during the ACM. The strenuous activities needed by the pilot to counteract the imposed G forces are physically demanding and can rapidly lead to physical impairment possibly compromizing his combat performance. In the present F-15 flying environment, pilots are reported to be very fatigued; also several episodes of loss of conciousness during G maneuvers have occurred (53).

Several methods are available to the pilot to resist the effects of G. All pilots of high performance aircraft wear an anti-G suit which supports the circulatory system of the legs and abdominal region (14, 17, 18, 19, 46, 55). The F-16 aircraft has a seat with a back angle tilted to 30° from the vertical which appears to have some value as an anti-G device (13, 16). On the other hand, although positive pressure breathing is being evaluated as a means of improving G tolerance (59), and the effects of controlling environmental and body temperatures on G tolerance have been studied (2, 12, 41, 47), these methods are not available to the pilot at this time. However, the pilot of today is capable of physically resisting the effects of G by utilizing the M-1 maneuver; and this capability is the most important G resistance method available to pilots of all high performance aircraft.

The M-1 is a respiratory/muscular effort[3/] (18) used by pilots to maintain conciousness and adequate vision during high G maneuvering flight. The muscular involvement for the M-1 involves the abdomen, diaphragm, chest, arms, and legs. The abdominal contraction prevents the pooling of blood in the abdominal region and aids in central venous return thereby helping to maintain cardiac output. At the same time the chest muscles are contracted to produce a forceful expiration, however, this is done against a closed or partially closed glottis so the intrathoracic pressure is elevated thus raising arterial pressure and maintaining eye and cerebral blood circulation. These abdominal and chest contractions are supplemented by tensing of the shoulder, arm, and leg muscles. The isometric contraction of just one arm muscle by itself will cause a rise in systolic blood pressure (4, 27) and probably leg tensing aids the anti-G suit in preventing pooling of blood in the lower extremities as well as aiding venous blood return to the central circulation.

At low G loads (4.5 to 6 G) with a functioning anti-G suit; shoulder, arm, and leg tensing without abdominal or thoracic involvement is adequate to maintain vision. Therefore, in the 4.5 to 6 G range and below, the M-1 can be limited to only extremity tensing thus allowing less rapid development of fatigue. However, at G loads greater than 4.5 to 6, abdominal and thoracic involvement are required to prevent the loss of vision and conciousness.

The above discussion establishes the importance of the M-1 and muscle tensing in resisting the effects of G. It is also evident that the kind of muscle involvement necessary for the M-1 is a static high intensity contraction that will support the circulatory system both mechanically and reflexly.

This kind of muscular tension is developed by training against a high resistance (heavy weights). The dynamic moderate intensity type of muscle training inherent in a running training program has little carryover to the kind of contractions necessary to resist high G loads. Applying a weight training regimen, an individual is "trained to strain." This kind of neuromuscular involvement is necessary to efficiently affect both the movement of a heavy weight and to counter the effects of G load. In addition, training with high intensity contractions is dependent upon the anaerobic energy producing enzyme systems of the muscles; a condition that will aid in G resistance when body muscles are statically contracted for periods of 5 or 6 seconds or longer with the development of muscle ischemia.

By way of contrast, a tenet of long distance running training requires relaxation during the exercise. The importance of this requirement was suggested when some of the group R subjects complained of difficulty in riding the centrifuge because they had to make a conscious effort to strain their muscles--a condition to which they were unaccustomed. Additionally, the running training programs "trains" the aerobic enzyme systems, a condition which will be beneficial when contraction intensity is low to moderate and blood flow is not restricted--conditions unlike those which exist when resisting the high G environment. The relatively low blood level of lactate in all three groups of subjects at the end of a fatiguing ACM exposure (15) also is indicative that there is sufficient oxidation during the ACM exposure to prevent lactate accumulation. Similar lactate levels in the 3 groups of subjects, including the runners with increased aerobic capabilities, at the end of the SACM again indicate the unimportance of the glycolytic aspect of aerobic capacity in ACM tolerance (Table XIII).

If exposure to high G was limited to less than 10 sec followed by a prolonged period (of 30 to 45 sec) of rest at low to moderate G, then a single near maximal M-1 would be adequate for the pilot to remain functional. In the past, this type of limited high G ACM was typical because aircraft were not capable of sustaining high G loads without losing energy (airspeed or altitude) which had to be gained back before another high G exposure could be achieved (thrust available was much less than thrust required in a high G situation).

However, today's high performance aircraft with their lower wing loading and more fuel efficient high thrust engines are capable of sustaining up to 9 G for prolonged periods of time. With this capability, the ACM is composed of repeated episodes of high sustained G (HSG), in which the pilot must be capable of functioning.

In this HSG environment, the ability to perform an efficient M-1 is vital. The pilot must perform the M-1 with an intensity that will allow him to have adequate vision for his inflight situation, repeating the maneuver at approximately 3 to 5 second intervals for the duration of each G exposure--several HSG exposures may occur over a period of many minutes. In order to achieve such performance, the pilot must learn to "tailor" his muscular contractions for the intensity of the G load; i.e. he must not overstrain because of fatigue development. Tailoring M-1 intensity to control the degree of loss of peripheral vision to approximately 50% is common among pilots regularly exposed to high G. My own personal experience as an Air Force pilot has taught me to control my visual field by simply varying the intensity of my M-1 and muscle contractions. Additionally this technique of controlling M-1 intensity is taught to individuals who ride the USAFSAM centrifuge as research subjects.

If a pilot has trained his muscles for strength and repeated high intensity contractions, he will be able to maintain vision with a lower percentage of maximal voluntary contraction (MVC) thereby sustaining the contraction longer (4) with a more rapid recovery (30). Additionally, even though specific information is not available, as an individual becomes stronger he should be capable of tolerating increasingly higher G loads.

Our study suggests that the most important muscles in determining G (SACM) tolerance are the abdominals and the biceps. These are also the muscles which probably are the greatest contributors to the M-1. Interestingly, the biceps group are used in pulling back on the control stick during high G loading of an aircraft. The stick force required to maintain a high G loading is proportional to G and can be as high as 40 to 50 pounds. In addition, tensing upper body muscles will reflexly increase systolic blood pressure, however, at high G this reflex is probably minor in considering the physiology of anti-G.

The strength of the muscles involved in the leg and bench presses, while participants in low to moderate G resistance (leg and upper body tensing), are probably of lessor importance in maintaining cerebral blood pressure at high G than are the abdominals and biceps. The support of the circulatory system below the heart with the aid of the anti-G suit is a function of leg muscles with cycles of contraction and relaxation aiding venous blood flow through the legs.

The G profile used in this study was designed to have the general characteristic of the inflight ACM environment. Previous research to determine G tolerance relationships with physical condition usually used relaxed subjects (24, 25, 43, 49). With the subject relaxed, G tolerances are a function of resting arterial blood pressure, age, body size (72), and cardiovascular baroceptor reflexes (4, 63). Additionally, relaxed tolerances are of low to moderate G intensity which are not directly related to the ACM environment of high performance aircraft (24, 25, 43, 49). In the ACM environment, the pilot actively resists the effects of high G, and the rate of change of G will be varied and can be rapid—6 G per sec onset rates are common in the F-15 (Fig. 1).

Consequently, the use of relaxed tolerance criteria as quantifiers of ACM tolerance are not appropriate.

In other studies where high G levels were used, G tolerance was defined as the maximum G load that a subject would voluntarily sustain in a single constant G-level exposure--frequently called high sustained G (24, 25, 38, 42, 43, 49, 71). In the ACM environment, G loads will be high but also will be varied with low G and these repeated many times. In the ACM environment, it is expected that peaks of high G will exist as part of a continueum of variable G loads ranging from 1 or 2 $-G_z$ up to about +9 or 10 G_z with much of the exposure time in the range of +3 to 8 G_z.7/ Consequently a constant long duration high G load is not a good simulation of the ACM environment. A centrifuge profile of a slow G onset to a low G plateau has also been utilized to test G tolerance (10, 34, 67) however, this too, is not applicable to the ACM environment.

The G profile used in this study, alternating 15 second plateaus of high and low G with rapid changes between plateaus was developed because it has all of the basic characteristics of an actual ACM, and measuring the time to fatigue that each subject achieved made the test quantifiable. The high G plateau of 7 G is a G load where the subject must perform an M-1. The 15 second plateau is long enough that three to five cycles of the M-1 are required by the subject during the plateau, but not of a duration that would be significantly different than might be expected in actual flight. The 4.5 G plateau allowed the subject a period of rest--not fully relaxed, yet leg tensing alone with the anti-G suit, but without the M-1, was sufficient to tolerate the G load. Also while at 4.5 G the subject is sufficiently active so as to be prepared for the onset of the next 7 G plateau.

Of course the most important feature of the SACM profile, was the time to fatigue used as the criterion for quantifying tolerance. An indication of the validity of fatigue as a valid criterion, repeatedly recognized by the subject, is the similarity of fatigue scores of the 3 experimental groups at weeks 1 and 12. Recently, the fatigue end point of the ACM has been validated using heart rate recovery, various seat back angles, and repeated SACM exposures (20). This ACM profile is routinely used at the School of Aerospace and has been found to be of value in measuring anti-G methods and equipment (20, 58).

The importance of the findings of this study, that weight training can significantly improve SACM tolerance, is of considerable importance to the fighter pilot of high performance aircraft. This experiment has identified ways by which pilots will be able to more easily tolerate the ACM environment. Since the pilot will be less fatigued, he should be able to direct more effort towards mission performance. Also a conditioned pilot will be able to press an ACM engagement longer and at a more intense level--improving his chances of success and survival.

Weight-trained individuals clearly demonstrated a reduction in fatigue under similar workloads in this study. In week 11, the weight-trained subjects completed the same duration of SACM they had accomplished in week 1 when they were not strength trained, with significantly less fatigue (Table XII). Also, although the members of group W rode longer in week 12 than they did in week 1, their level of fatigue was the same as reflected in the fatigue scores. It is apparent that the reduced effort required to tolerate the SACM by the weight trainers after they were weight trained allowed them to sustain the G stress for a longer time before reaching their point of fatigue.

If fighter pilots were to engage in a weight training program such as suggested by this study, the first effect expected would be a reduction in fatigue following high G missions--either air-to-air (F-15 and F-16) or air-to-ground engagements (A-10). In addition, the weight trained pilots would be expected to have improved survivability and better mission performance. It would be expected that the incidence of loss of conciousness and blackout should be lower among the weight trained pilots.

In actual air-to-air combat, the weight-trained pilot should perform significantly better since he could pull higher G and probably experience less fatigue. In air-to-ground engagements the weight trained pilot should have the capability when necessary to disengage more quickly, to maneuver within a smaller volume of airspace during an engagement, and to make tighter and more prolonged defensive turns--maneuvers useful is complicating ground-to-air missile guidance.

The key to increased G tolerance is the ability for a pilot of fighter aircraft to function at any given G loading, using a lower percentage of his maximal voluntary contraction (MVC). Since, during a prolonged engagement, the weight-trained pilot will take longer to become fatigued he will function longer at a high efficiency level. The delayed onset of fatigue will be the result of both a lower MVC percentage required for the M-1 at high G loads and a sparing of the M-1 effort with leg muscle contraction at moderate G loads. While the pilot is not performing the M-1, the abdominal and chest muscles will achieve a greater level of recovery because of the lower percentage of MVC used at moderate G loads. An additional benefit of utilizing a lower percentage of MVC is that the pilot can direct an increased amount of attention to his flying tasks which could increase his performance.

In order for the fighter pilot to become weight trained he must follow some specific program. At a minimum, the training program must involve those muscles which have the greatest influence on ACM tolerance. Additional muscle involvement in the training program is useful to improve whole body strength capacity and strength endurance and thereby take advantage of the synergistic benefits identified by this study.

The following training motions, grouped by priority, are suggested for inclusion in any training program.

First priority: (a) sit up with the weight held on the chest or back of the head; (b) arm curl; and, (c) bent over row with knees bent and forehead supported. These motions train the muscles most used by the pilot in performing the M-1 and flying the airplane (control the stick position).

Second priority: (a) leg press; (b) bench press (push up); and, (c) pull down (chin up). These motions train the muscles of the legs, arms, and chest muscles which assist in the support of the circulatory system. Of course, the inclusion of additional motions in any program accomplish overall conditioning and be useful in filling out a circuit.

All lifting motions should include sets of at least ten repetitions (reps) and should be performed three times per week. The weights used should be moderately heavy (50 to 60% of the determined 1RM) at the start of the training program, and then increased to 80% of 1RM as coordination and strength are developed. The weights should be increased creased when more than 10 reps of a motion can be readily accomplished. Single sets of 10 reps may be utilized or, as used in this study, three sets of 10 reps with increasing 1RM percentages. The number of sets is less important however than participation in a regular strenuous training program. On the other hand, it is important that the set of 10 reps not be performed at a rapid rate.

To tolerate the ACM environment, repeated reps of the M-1 are required, therefore, it is imperative that the weight training regimen approximate these same requirements. The pilot should remember that the development of straining endurance as well as strength is essential for best tolerances in the ACM environment. Between sets, a rest of at least 1-1/2 minutes is best. It is not necessary to train more often than every other day. A thorough warm up using light weights and slow stretching before each day's training program is very important to prevent muscle soreness or injury.

Although this study has demonstrated that a program of weight training can affect an increase in SACM tolerance time, and that tolerance to $+G_z$ load is most strongly related to abdominal and arm strength, further study is required to optimize the training requirements needed to increase ACM tolerances. Such a study would determine which weight training motions (singly or in combination) are most effective in increasing ACM tolerance, e.g., this study would train subjects with only the sit up, only arm curl, and only the bent over row. Additionally, the combination of reps and weights most effective in improving ACM tolerance should be considered in another study. Whereas 1RM once a week can produce an increase in strength (8) such a simplified program may be ineffective on ACM tolerance because of the differences in the time-intensity relationships between 1RM and ACM tolerance. Also a weight training program specifically designed to determine the maximum rate of strength increase (5, 7) may not be optimum for developing ACM tolerance because of the muscular endurance factor necessary in withstanding the ACM environment.

Isometrics is another type of strength training which might be assessed. The training motions so far described are isotonic or dynamic motions and in most cases utilize the full range of joint motion and change in muscle length. The M-1 and muscle tensing used in resisting G is essentially a static (isometric) contraction--it is known that training statically increases static strength more effectively than training dynamically (6). Recently, Greenleaf et al (33) demonstrated that isometric exercise could prevent some loss of relaxed G tolerance resulting from bed rest.

An interesting aspect of the present study was the time relationship of the sit up weight training which tended to be sigmoidal--a rapid increase in sit up performance occurred early in the training program followed by a leveling off in sit up capability near the end of the study (Fig. 13). This early rise in sit up strength appears to be a function of initial abdominal weakness in our subject population--the result of infrequent muscle tensing in day-to-day living. Because of the high correlation found in this study between abdominal strength and SACM tolerance, training with only sit ups may be an excellent way to achieve a quick improvement in tolerance to the air combat maneuvering environment.

FOOTNOTES

1/ Tolerance to G is generally measured on persons who relax during exposures to acceleration. These tolerance determinations usually use visual criteria as endpoints (grey-out or peripheral light loss-PLL; black-out or central light loss-CLL). The laboratory at USAF School of Aerospace Medicine (USAFSAM) generally uses 100% PLL with 50% CLL. Details regarding methods of measuring relaxed G tolerance are available in Coburn (23) and Parkhurst et al. (55). Two types of G exposure (classified by rate of G onset) are generally used on subjects to measure relaxed G tolerance: (a) ROR with G onset rates of 1 G per sec; and (b) GOR with 0.1 G per sec onset rate. The GOR tolerance is usually about 1 G higher than ROR tolerance. The slower G onset rate allows for cardiovascular reflexes to occur resulting in an increase in the systemic arterial blood pressure. Details regarding the difference in these two methods of G tolerance determinations are available in Edelberg et al. (26).

2/ The anti-G suit is a pneumatically inflated garmet which applies pressure to the lower part of the body. This pressure on the abdominal area and legs increases eye-level arterial blood pressure thereby raising G tolerance in the relaxed subject by approximately 1 G. For details regarding the function and use of the anti-G suit, the reader is referred to Burton et al. (19) and Burton and Krutz (17).

3/ The M-1 is a voluntary respiratory/muscular effort which elevates the systemic arterial blood pressure at eye level so that vision and cerebral blood flow are adequately maintained during high G exposure. Details regarding the M-1 are available in Burton, et al. (19).

4/ The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 80-33.

5/ Universal Gym Products, 17352 Von Karmon, Irvine, Calif. 92714.

6/ Mr. Clarence Theis of USAFSAM (Crew Technology Division) made all anthropometric and body volume measurements used in this study. His cooperation is gratefully acknowledged.

7/ Current A-10 experience has produced 30 minute profiles with rapid G variations ranging between +2 and 6 G_z; and current F-15 experience has produced 10 minute profiles with a $+G_z$ range of +2.5 to 7.5 G_z (personal communication, Dr. K. K. Gillingham, USAFSAM).

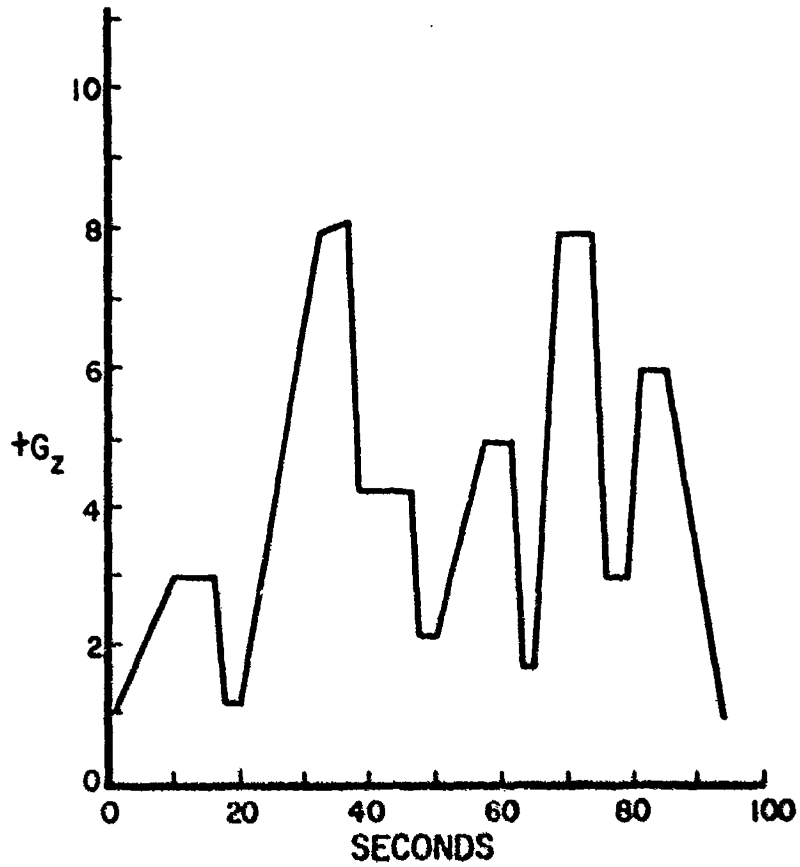

Figure 1: G profile of a simulated aerial combat maneuver of an F-16 (16). This profile was developed from accelerometer records of an F-4 aircraft in a simulated aerial combat engagement and advise from pilots of the Lightweight Fighter Joint Test Force, AFFTC, Edwards AFB, CA.

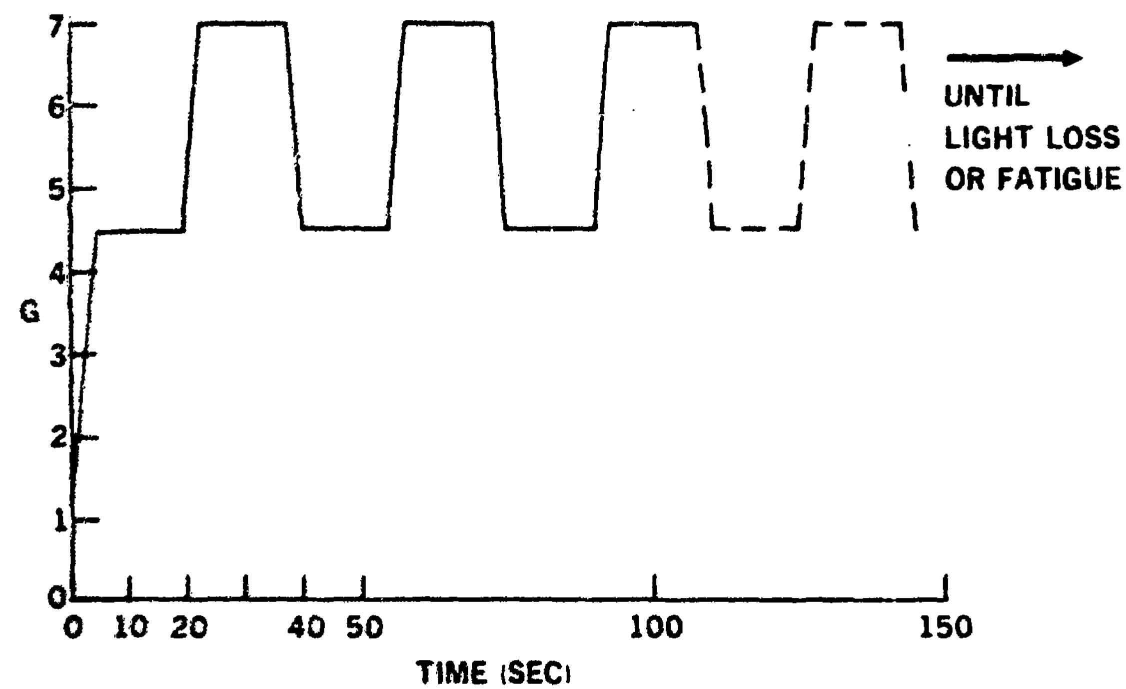

Figure 2: The simulated aerial combat maneuver (SACM) is 4.5 G for 15 sec followed with 7.0 G for 15 sec, continuing this G cycle until the subject stops the centrifuge because of fatigue or loss of vision because of the blackout phenomenon. G tolerance is measured as the duration of time (sec) the SACM is endured by the subject.

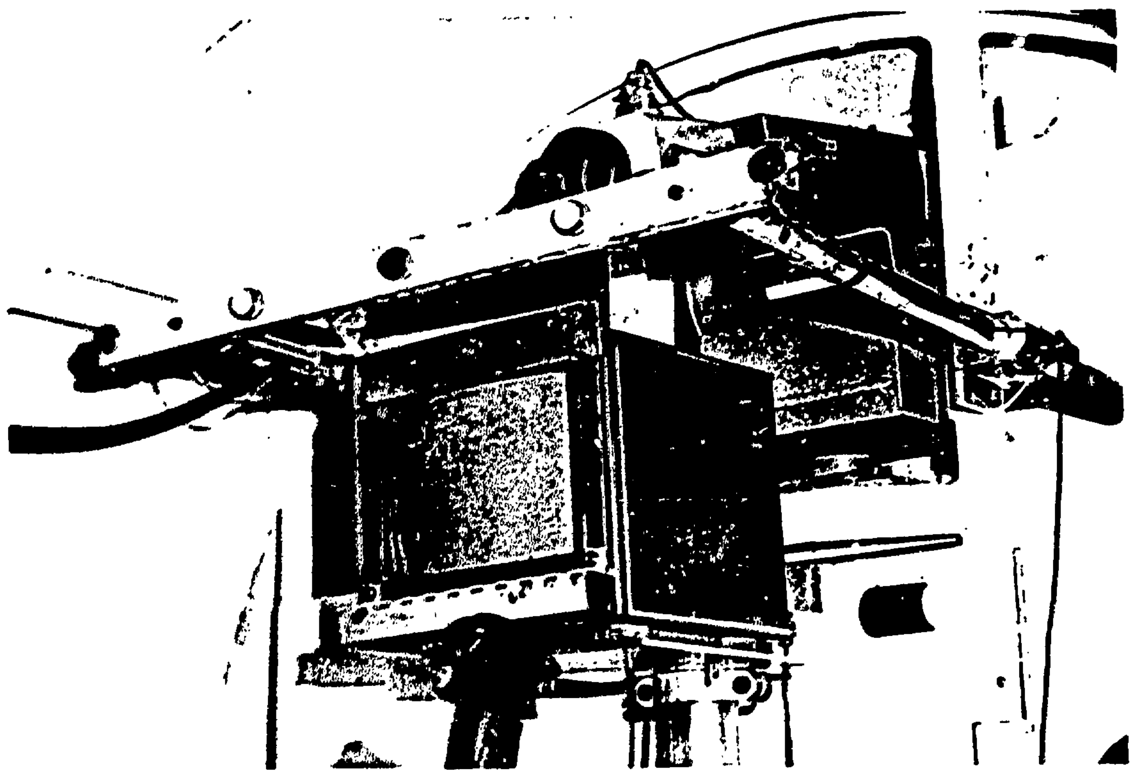

Figure 3: The light bar is shown above the oscilloscope 30 in. in front of and slightly above the subject's eyes. The 2 peripheral dark lights are green in color and used to judge peripheral light loss (PLL). The 2 peripheral white lights are not used. The center dark light is red and used to quantify central light loss (CLL).[1]

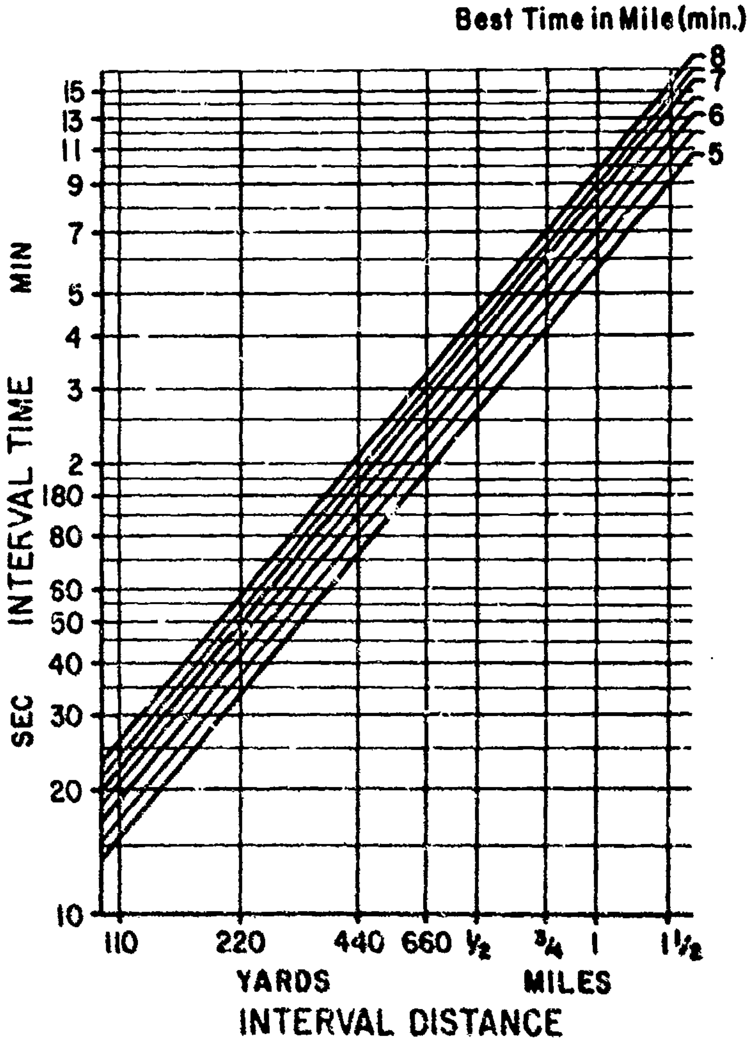

Figure 4: Interval distance-time chart developed from the data of Fox and Mathews (28) and Adams (1).

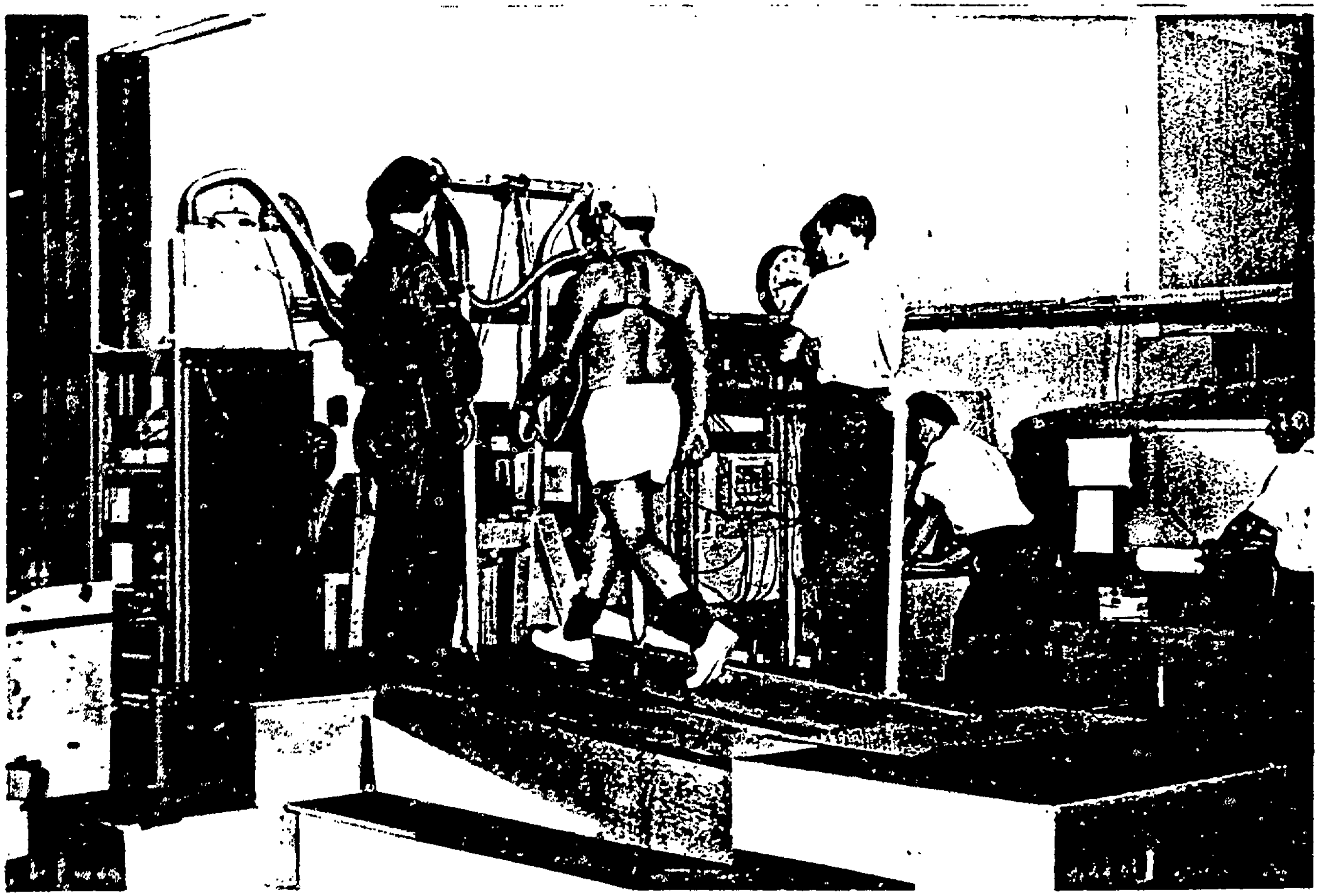

Figure 5: A subject is shown walking on the treadmill in a $\dot{V}_{O_2}$ max determination.

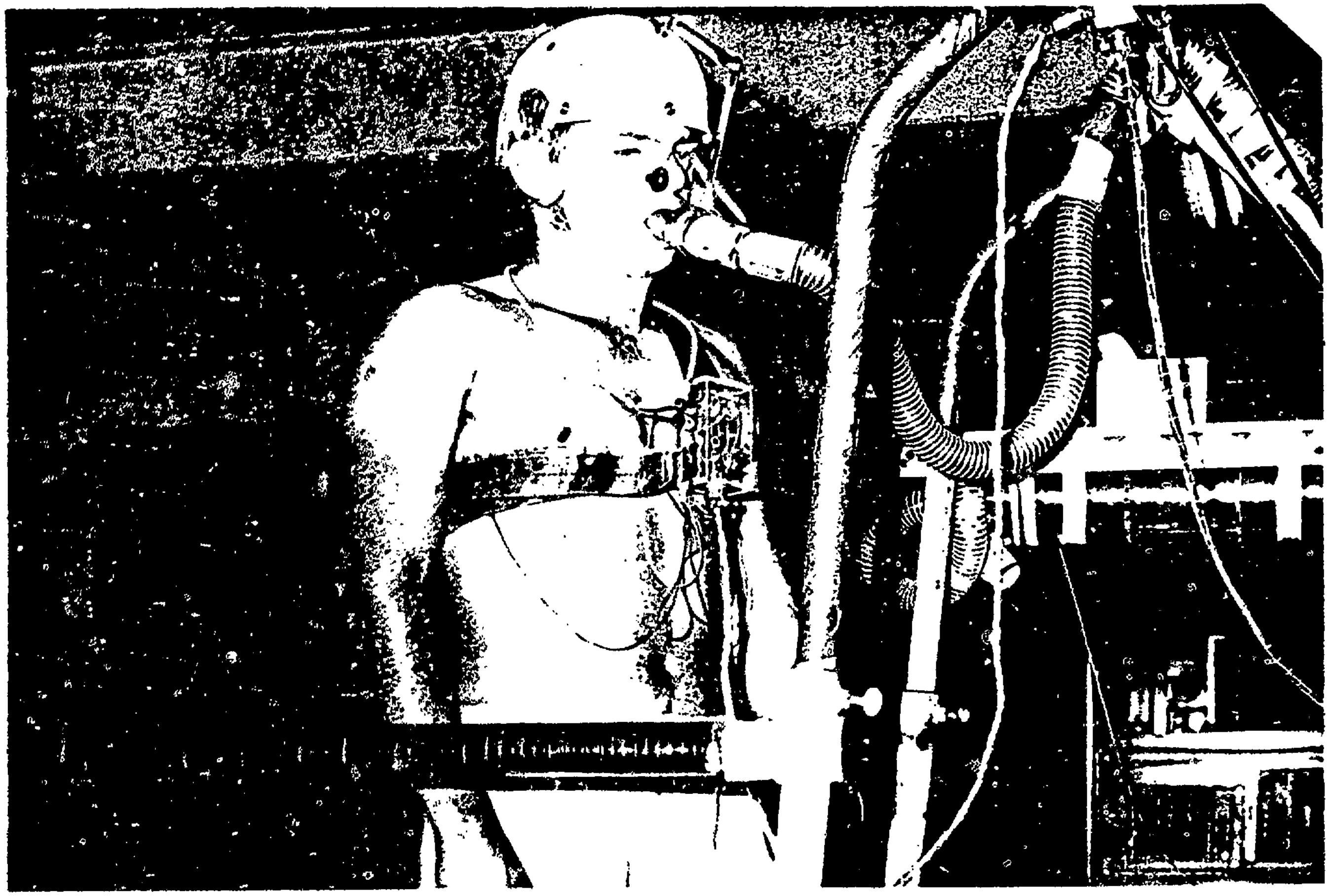

Figure 6: An instrumented subject is monitored just before beginning a $\dot{V}_{O_2}$ max measurement. Shown is the expired gas collection system. The electrocardiotach apparatus is located on the chest with electrocardiogram leads attached to the skin of the subject.

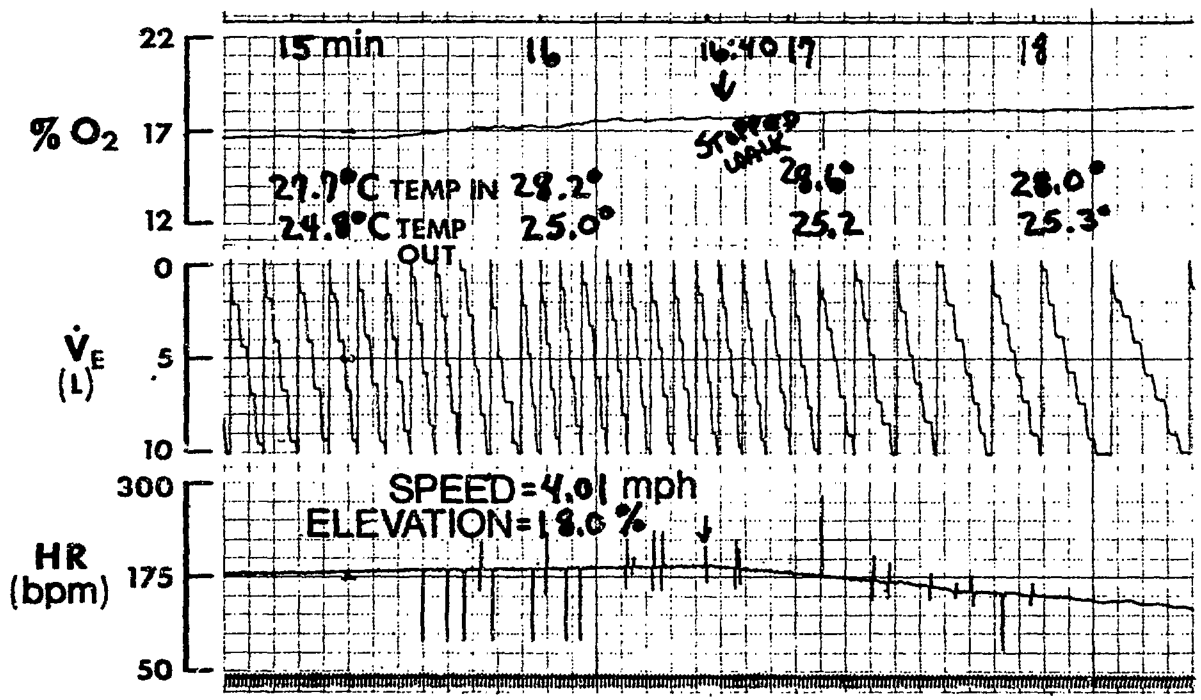

Figure 7: Example of a strip chart recording taken during $\dot{V}_{O_2}$ max determination. Consult the text for details.

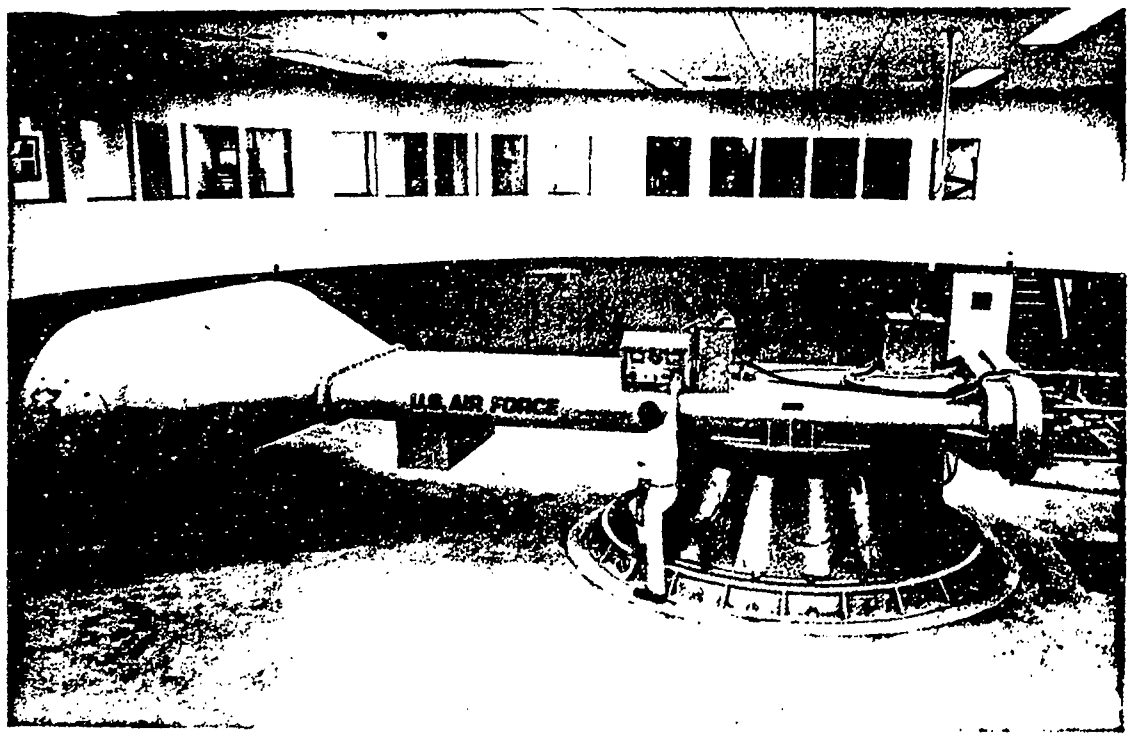

Figure 8: The USAFSAM centrifuge has 6.1 m radius. The human-use gondola is shown on the left. Windows directly above the center of the centrifuge indicate the location of the centrifuge control room. Entrance to and from the centrifuge room is through the door and stairs shown on the right just above the centrifuge.

Figure 9: Shown is a subject instrumented for G exposure with ECG leads (sternal and biaxillary), anti-G suit, and restraint harness.

Figure 10: A subject is seated in the centrifuge gondola ready for a G exposure. The centrifuge brake is in his left hand. An ECG electrode is shown on his chest (note arrow). The subject is facing the light bar (Fig. 3)—note arrow on upper right corner. The ear oximeter is shown positioned on the right ear.

Figure 11: A subject is shown on the television monitor (as seen by the central observer and medical monitor) performing an M-1 during the SACM.

Item Nr.	Better Than	Same As	Worse Than	Statement
1				Very lively
2				Extremely tired
3				Quite fresh
4				Slightly pooped
5				Extremely peppy
6				Somewhat fresh
7				Petered out
8				Very refreshed
9				Fairly well pooped
10				Ready to drop

Figure 12: A fatigue score was developed from this fatigue checklist after its completion by each subject. Details regarding the use of this checklist are found in the text.

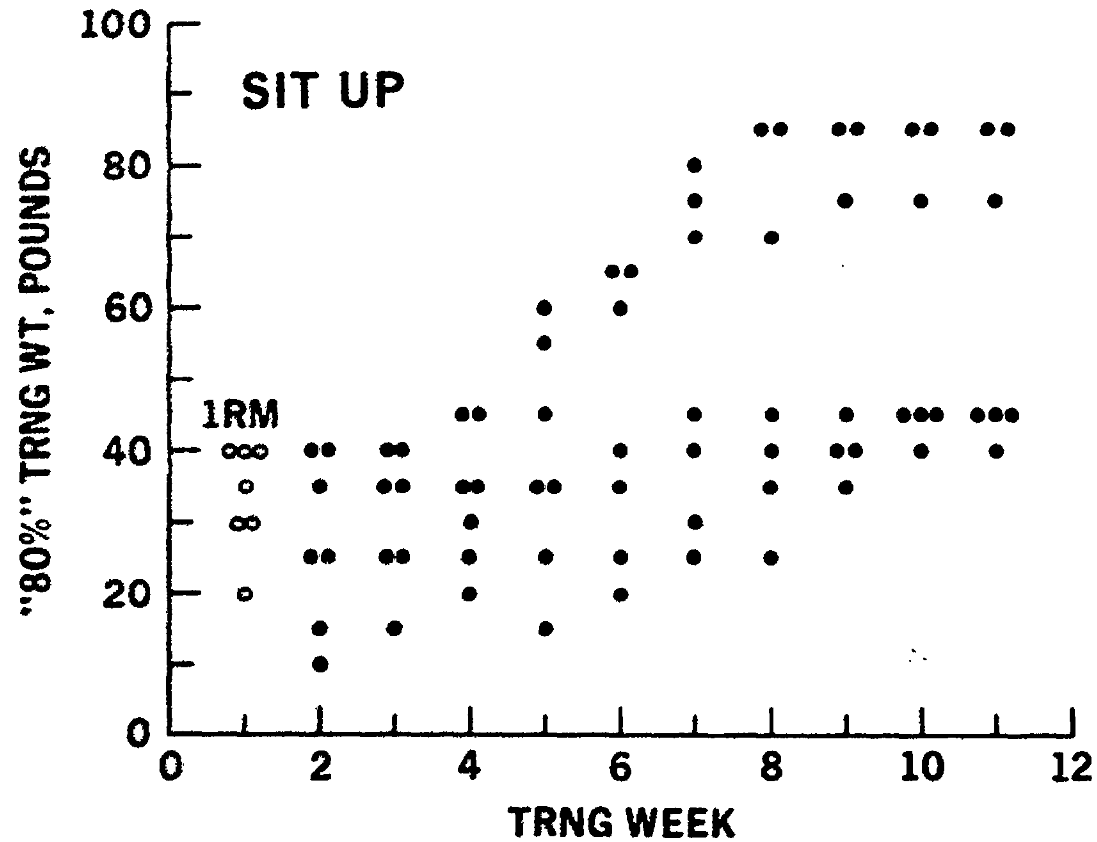

Figure 13: Individual training weights are shown for each week of the study. It appears that near the middle of the schedule (week 6) 2 groups developed relative to abdominal strength—the strong group used 80 lbs for training whereas the other groups had an 80% 1RM of 40 lbs.

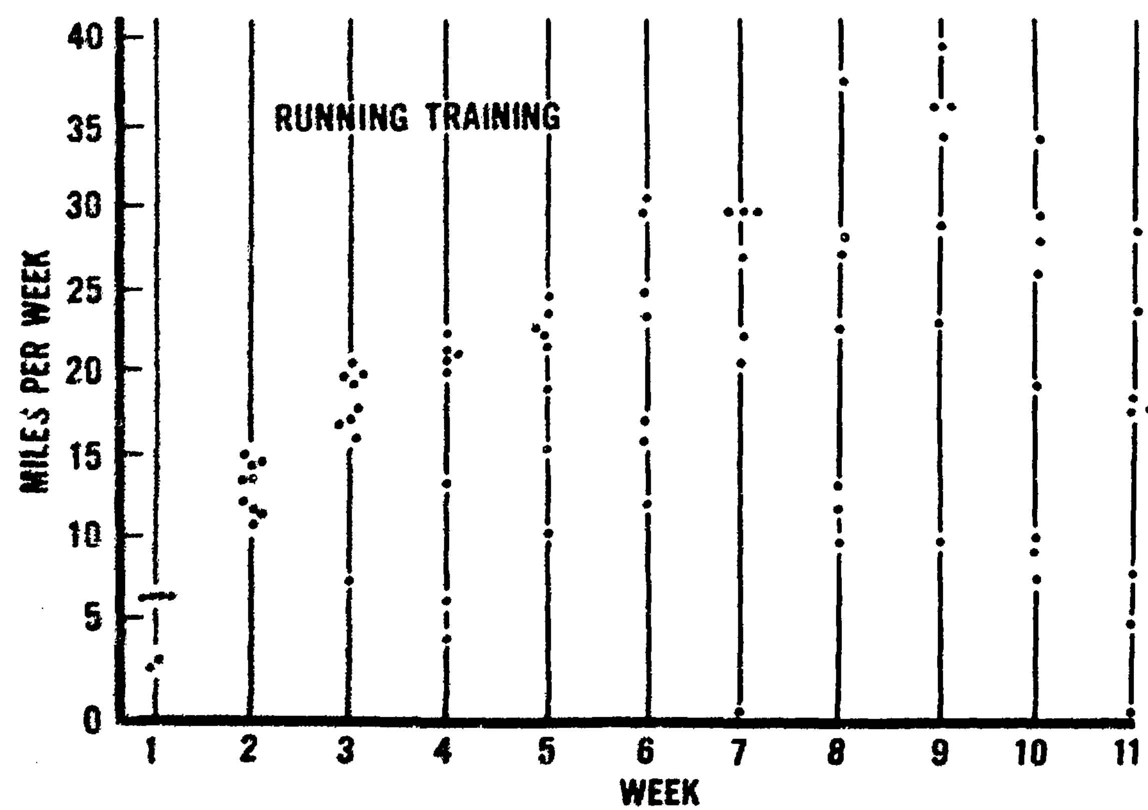

Figure 14: Individual subject running training is shown as total miles run per week. Group R training was most consistent through week 6, although some subjects continued to increase their running training up through week 10.

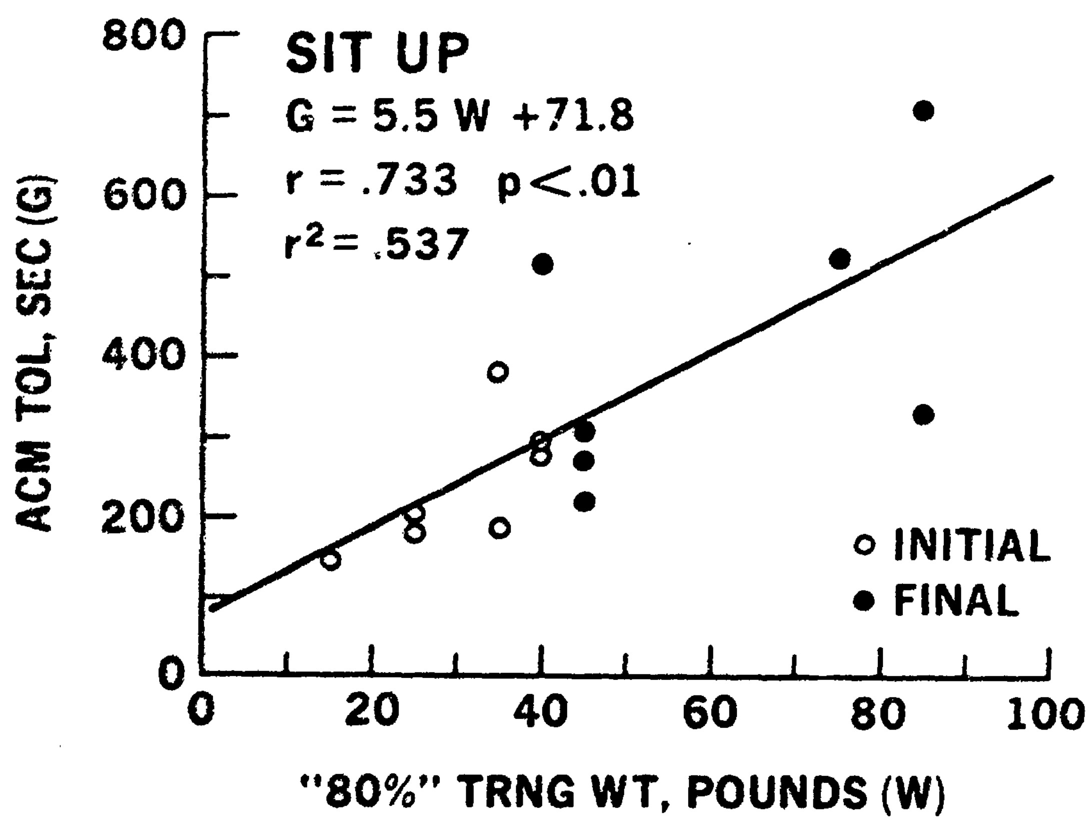

Figure 15: The 80% training weights (function of 1RM) for the sit up is correlated with SACM tolerance using the initial individual subject values (week 1) with their final values (week 12).

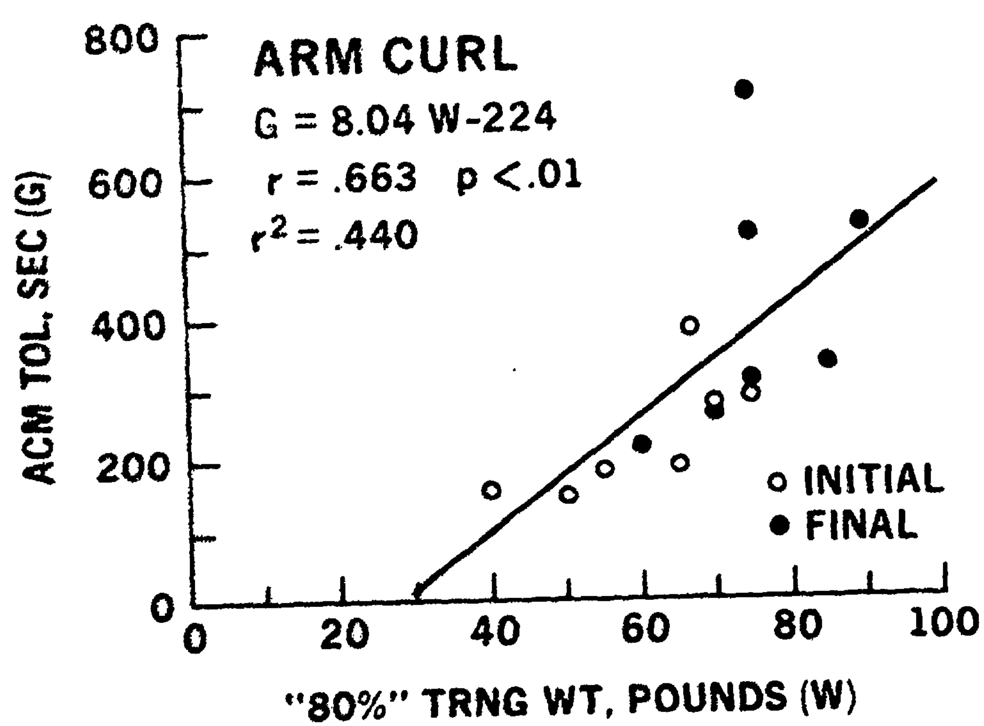

Figure 16: The 80% training weights (function of 1RM) for the arm curl is correlated with SACM tolerance using the initial individual subject values (week 1) with their final values (week 12).

Table I: Physical characteristics of the experimental subjects, identification number, exercise category, and G tolerance (sec) attained through SACM training are shown for the three experimental groups.

Subject Number	Exercise[a] Category	Age (Yrs)	Height (Cm)	Body Mass (Kg)	SACM Tolerance (Sec)
Group I (week 1)[b]					
01	C	20	162	58	413
11	R	18	165	58	364
21	W	20	175	78	189
02	C	18	181	79	107
12	R	19	182	68	104
22	W	18	172	65	147
23	W	19	178	60	183
03	C	18	170	68	284
13	R	18	178	66	233
Group II (week 2)					
24	W	18	177	73	157
04	C	18	172	77	204
15	R	21	167	64	149
25	W	20	181	80	384
05	C	19	178	62	111
16	R	18	172	73	162
17	R	18	171	60	96
Group III (week 3)					
06	C	19	184	69	226
18	R	21	192	89	146
27	W	18	178	71	276
28	W	18	176	71	289
07	C	28	176	62	134
19	R	21	176	72	186
08	C	21	178	70	117
09	C	22	171	65	155

[a] C = control (no exercise); R = runners, and W = Weight trainers.

[b] grouped for logistical purposes. Each group had 10 subjects at the beginning of the study.

Table II: Centrifuge Indoctrination, Training Program and Data Collection Relative to Types of G Exposures. The training program ran for 5 weeks. Shown are the specific centrifuge runs/exposures relative to the rate of G onset, use of G-suit, and whether the subject was relaxed or straining (M-1).

Run No.	Conditions[a]
Indoctrination:	
1	GOR, Relaxed, No G-suit
2	ROR, 2.5 G-15 sec, Relaxed, No G-suit
3	ROR, 3.0 G-15 sec, Relaxed, No G-suit
4	ROR, 3.4 G-15 sec, Relaxed, No G-suit
First Training Exposure:	
1	GOR, Relaxed, No G-suit pressure
2	GOR, Relaxed, No G-suit pressure
3	GOR, Relaxed, With G-suit pressure
4	ROR, 4.5 G-30 sec, straining
5	ROR, 4.5-7-4.5-7 G, straining[b]
	or ROR, 4.5-6-4.5-6 G, straining
Second Training Exposure:	
1	GOR, Relaxed, No G-suit pressure
2	GOR, Relaxed, with G-suit pressure
3	ROR, 4.5 G-30 sec, straining
4	ROR, 4.5-7-4.5-7 G, straining[b]
5	ROR, 4.5-7-4.5-7 G, straining
Third through Sixth Training Exposures and Data Collection:	
1	ROR, 3 G-30 sec, straining
2	ROR, $(4.5\text{-}7\ G)_n$ until fatigue, straining

[a] GOR = G Onset Rate of 1 G per 15 sec to 100% PLL with 50% CLL. ROR = Onset Rate of 1 G per sec to a predetermined G profile with the subject relaxed and no anti-G suit or with the subject straining (M-1) and wearing an inflated anti-G suit.

[b] early ACM training exposures were limited to two 6 or 7G peaks.

Table III: Weekly Running, Training Schedule for the Runners Group.

Week	First Session (Morning)	Second Session (Afternoon)
1	Run-walk 1 mi - stretch - run-walk 1 mi	Warm up: 880 yd Intervals: 1540 yd
2	Continuous run: 2 mi Fri - timed mile[a]	Warm up: 1320 yd Intervals: 1 mi
3	Continuous run: 2½ mi	Warm up: 1 mi Intervals: 1¼ mi
4	Continuous run: 3 mi Fri - timed mile	Warm up: 1 mi Intervals: 1½ mi
5	Continuous run: 3 mi	Warm up: 1 mi Intervals: 1 3/4 mi
6	Continuous run: 4 mi Fri - timed mile	Warm up: 1 mi Intervals: 2 mi
7	Continuous run: 4 mi	Warm up: 1 mi Intervals: 2 mi
8	Continuous run: 5 mi Fri - timed mile	Warm up: 1 mi Intervals: 2 mi
9	Continuous run: 5 mi	Warm up: 1 mi Intervals: 2 mi
10	Continuous run: 6 mi Fri - timed mile	Warm up: 1 mi Intervals: 2 mi
11	Continuous run: 6 mi	Warm up: 1 mi Intervals: 2 mi
12	Continuous run: 6 mi	Warm up: 1 mi Intervals: 2 mi

[a] The time recorded for the timed mile was used to establish the pace for interval running--see Fig. 4 and Table IV.

Table IV: Interval running pace schedule developed from figure 4.

	Interval Distance (yds)							
	110	220	440	660	880	1320	1 mi	1½ mi
Mile Time	Interval Times (min:sec)							
4:45	:14	:30	:65	1:42	2:19	3:34	4:58	7:40
5:00	:15	:32	:69	1:48	2:28	3:47	5:17	8:09
5:15	:16	:34	:73	1:54	2:36	4:00	5:36	8:38
5:30	:17	:36	:77	2:00	2:45	4:15	5:55	9:07
5:45	:18	:38	:81	2:07	2:54	4:30	6:15	9:36
6:00	:19	:40	1:25	2:14	3:03	4:44	6:34	10:05
6:15	:20	:42	1:29	2:20	3:12	4:58	6:53	10:34
6:30	:21	:44	1:33	2:26	3:21	5:12	7:12	11:03
6:45	:22	:46	1:37	2:33	3:30	5:26	7:30	11:32
7:00	:23	:48	1:41	2:39	3:38	5:39	7:48	12:01
7:15	:23	:49	1:45	2:44	3:46	5:51	8:06	12:30
7:30	:24	:51	1:49	2:50	3:54	6:04	8:25	13:00
7:45	:25	:53	1:53	2:57	4:03	6:17	8:44	13:28
8:00 & up	:26	:55	1:57	3:03	4:12	6:03	9:03	13:57

Table V: Schedule for interval training derived from data in Fox and Mathews (28) and Adams (1). Relief Interval Time specifies the types and durations of relief relative to various interval running distances--HR = heart rate (beats per min).

Week	MON	TUE	WED	THUR	FRI
1				3 x 110 1 x 220 3 x 110	2 x 110 1 x 440 1 x 220
2	3 x 110 1 x 220 3 x 110	2 x 220 1 x 110 1 x 110	3 x 220 1 x 110 3 x 220	1 x 220 1 x 220 1 x 110	2 x 440 2 x 220 1 x 110
3	2 x 220 2 x 440 1 x 220	1 x 440 1 x 220 3 x 220 2 x 110	2 x 440 1 x 220 2 x 110	1 x 220 1 x 110 1 x 220	2 x 440 1 x 220 1 x 110
4	2 x 110 2 x 440 1 x 440 3 x 220	3 x 440 5 x 220 3 x 110	1 x 660 2 x 440 3 x 220 4 x 110	1 x 660 2 x 440 3 x 220 2 x 220	2 x 660 1 x 220 4 x 110
5	1 x 440 4 x 220 4 x 220 4 x 110	1 x 660 2 x 440 5 x 220 4 x 110	1 x 660 2 x 440 4 x 220 6 x 110	1 x 880 1 x 440 4 x 220 4 x 220	2 x 660 4 x 220 3 x 220
6	2 x 660 4 x 220 3 x 220 4 x 110	3 x 660 1 x 440 4 x 220 2 x 110	1 x 880 1 x 660 1 x 220 3 x 220 4 x 110	3 x 660 1 x 440 1 x 220 2 x 110	1 x 880 2 x 660 3 x 220 3 x 220
7	2 x 660 1 x 660 4 x 220 6 x 110	1 x 880 2 x 660 2 x 440 2 x 220	1 x 1320 1 x 660 5 x 220 4 x 110	1 x 880 2 x 660 1 x 440 4 x 220	1 x 1320 2 x 660 4 x 220
8	1 x 880 2 x 660 4 x 220 2 x 110	1 x 1320 4 x 440 4 x 220	3 x 660 4 x 220 3 x 110 3 x 110	2 x 880 2 x 440 4 x 220	1 x 1320 2 x 660 4 x 110 4 x 110
9	2 x 880 1 x 660 1 x 220 2 x 110	2 x 660 2 x 660 1 x 440	1 x 1 mi 1 x 880 2 x 220 1 x 110	2 x 880 2 x 440 2 x 220 1 x 110	1 x 1 mi 2 x 660 2 x 220
10	1 x 1 mi 2 x 440 2 x 220	2 x 660 2 x 660 1 x 440 1 x 110	1 x 1½ mi 1 x 660 2 x 110	1 x 1 mi 2 x 880	1 x 1½ mi 1 x 440 4 x 110
11	2 x 660 2 x 660 2 x 220 1 x 110	1 x 1 mi 2 x 440 1 x 220	1 x 1½ mi 1 x 1½ mi	3 x 440 4 x 220 4 x 220 4 x 110	2 x 880 2 x 660 4 x 110
12	1 x 1½ mi 2 x 220 4 x 110	1 x 880 3 x 440 6 x 220	1 x 1½ mi 1 x 660 2 x 110	2 x 880 3 x 440 4 x 110	1 x 1 mi 2 x 880

RELIEF INTERVAL TIME

Distance	Work:Relief Ratio	Type Relief
110	1:3	Walking
220	1:2	Walking
440	1:1½	Jog:Walk (1:2)
660	1:1½	Jog:Walk (1:2)
880	1:1	Jog:Walk (1:3)
1320	3 min or HR <120	Jog:Walk (1:3)
1 mi	4 min or HR <120	Jog:Walk (1:4)
1½ mi	5 min or HR <120	Jog:Walk (1:4)

Time between sets:
Distance ≤880 - 3 min or HR <120
Distance ≥880 - 5 min or HR <120

Table VI: Specific Muscle Training Circuits used by the Weight Training Group.

Circuit 1	Circuit 2
1. Arm curl	1. Sit up
2. Standing press	2. Heel rise
3. Wrist roller	3. Head strap
4. Lat. pull down	4. Leg press
5. Bench press	5. Side-to-side bend
6. Erect row	6. Bent leg dead lift
7. Dumbbell high pull up	

Table VII: Branching Multistage Treadmill Test used in determining $\dot{V}O_2$ max on all subjects. Each test begins with the subject walking at 3.19 mph and at 0% slope, and continues by increasing slope or speed at two minute intervals. If at the stages indicated by ** the subjects heart rate was less than 140 beats per minute then the test was continued in the next branch, otherwise the same branch was continued until the subject was exhausted. This test protocol was developed at the Human Performance Laboratory of the University of California at Davis and has been the standard stress test there for several years.

		BRANCH II		BRANCH III		BRANCH IV		BRANCH V	
Stage	Time min	Speed MPH	Slope %	Speed MPH	Slope %	Speed MPH	Slope %	Speed MPH	Slope %
2	2-4	**							
3	4-6	3.19	0						
4	6-8	3.19	3.5	**					
5	8-10	3.19	6	3.63	3.5				
6	10-12	3.19	9	3.63	7	**			
7	12-14	3.19	12	3.63	10	4.01	7.5		
8	14-16	3.19	15	3.63	13	4.01	12	**	
9	16-18	3.19	17.5	3.63	16	4.01	15	5.21	12
10	18-20	3.19	20	3.63	19	4.01	18	5.21	16
11	20-22	3.19	22	3.63	22	4.01	20	5.21	19.5
12	22-24					4.01	22	5.21	22
13	24-26							6.20	22

TABLE VIII. The effects of physical training for 12 weeks on several physical and physiological parameters is compared between week 1 (pre; baseline) and week 12 (post) using paired t-testing. Shown are group means ± S.E. and % change in the parameter resulting from the training program.

Parameter	Controls (Group C)				Runners (Group R)				Weight Trainers (Group W)			
	Pre[a]	Post[a]	%Δ[b]	P[c]	Pre	Post	%Δ	P	Pre	Post	%Δ	P
Body Mass	67.8 ±2.5	67.9 2.4	0.2	NS	69.0 3.3	68.5 3.3	-0.7	NS	69.6 2.7	71.2 2.9	2.3	<.01
% Fat: Volume	13.3 1.7	11.1 1.2	-16.5	<.05	12.4 0.7	8.7 0.9	-29.8	<.01	16.7 2.8	13.9 2.9	-16.8	<.01
% Fat: ^{40}K	14.3 1.2	13.2 1.2	-7.7	<.05	14.0 0.9	12.5 0.9	-10.7	<.01	17.5 1.9	17.2 1.8	-1.7	NS
$\dot{V}_{O_2}$ max	47.3 1.4	46.7 1.5	-1.3	NS	49.2 1.0	52.9 1.4	7.5	<.05	47.7 1.5	47.0 2.1	-1.5	NS
Blood Vol	6.06 0.22	6.08 0.26	0.3	NS	5.77 0.19	6.20 0.18	7.5	<.01	5.66 0.22	6.05 0.20	6.9	NS
$+G_z$ Tol	195 34	242 39	24.1	NS	180 31	226 33	25.5	NS	232 33	411 67	77.2	<.05

a = Mean ± S.E.; Pre = Baseline (week 1); Post = End of Training (week 12); Body mass in Kg; $\dot{V}_{O_2}$ max in $ml \cdot min^{-1} \cdot kg^{-1}$; Blood Vol in liters; G Tol (SACM) in sec.

b = $\frac{\text{Post-Pre}}{\text{Pre}} \times 100 = \%\Delta$

c = Paired t-test; NS = not significant, P > 0.05.

TABLE IX: The effects of physical training for 12 weeks on body conformation is compared between week 1 (pre; baseline) and week 12 (post) using paired t-testing. Strength comparison was made for only the weight trainers. Shown are group means ± S.E. and % change in the parameter resulting from the training program.

Parameter	Controls (Group C)				Runners (Group R)				Weight Trainers (Group W)			
Muscle Size	Pre[a]	Post[a]	%Δ[b]	P[c]	Pre	Post	%Δ	P	Pre	Post	%Δ	P
Chest	91.6 1.66	92.2 1.46	.7	NS	92.8 1.50	91.8 1.49	-1.1	NS	92.4 1.95	96.3 2.09	4.2	<.01
Abdomen	77.3 1.81	77.2 1.63	-0.1	NS	77.4 1.22	76.6 1.09	-1.0	NS	79.8 2.09	80.4 2.22	0.8	NS
Biceps	32.4 0.75	32.2 0.75	-0.6	NS	32.2 0.72	31.6 0.57	-1.9	<.05	31.8 0.55	32.8 0.54	3.1	<.01
Thigh	55.0 1.22	54.5 1.06	-0.9	NS	56.2 1.30	55.2 1.30	-1.8	<.01	56.5 1.87	56.4 1.98	-0.2	NS
				Weight Trainer's Strength[d]								
Arm Curl	60.0 4.63	75.7 3.69	26.2	<.01				Bench Press	102.9 8.08	130.0 11.95	26.3	<.05
Leg Press	282.1 18.25	402.9 25.47	42.8	<.01				Sit up	30.6 3.50	60.9 7.79	99.0	<.01

a = Mean ± S.E.; Pre = Baseline (week 1); Post = End of Training (week 12); sizes are circumferences in cm; strength is in pounds; b = (Post - Pre/Pre) X 100 = %Δ; c = Paired t-test; NS = not significant P > 0.05; d = Strength not determined for groups C and R.

Table X. Regression analyses for $\dot{V}_{O_2}$ max, % fat, blood volume, and SACM tolerance relative to weeks of training—y = a ± bt where y = parameter as a function of t (weeks) with a as the intercept and b the slope (rate of change).

Group	$\dot{V}_{O_2}$ max[a]				% Fat[a]				Blood Volume[a]				SACM Tolerance[a]			
	a[b]	b[b]	p[c]	eq.#[d]	a[b]	b[b]	p[c]	eq.#	a[b]	b[b]	p[c]	eq.#	a[b]	b[b]	p[c]	eq.#
C	47.3	-.037	<.05	5	13.3	-.204	<.01	8	6.06	1.42	NS	11	181	4.3	<.01	14
R	49.2	.452	<.01	6	12.9	-.314	<.01	9	5.84	57.89	<.01	12	173	4.2	<.01	15
W	47.2	-.028	<.05	7	16.7	-.255	<.01	10	5.93	34.88	<.05	13	217	15.6	<.01	16

a = $\dot{V}_{O_2}$ max in $ml \cdot min^{-1} \cdot kg^{-1}$; % fat using body volume methcd; blood volume in L; and SACM tolerance[a] in sec.

b = y = a ± bt where y = parameters as a function of the week 1 intercept (a) ± rate of change (b) per week (t).

c = p = probability of chance occurrance.

d = eq.# = number of specific equation for reference purposes in the text.

Table XI. Regression Analysis for Weight Trainer's SACM (G) Tolerance (sec) as a function of "80% of 1RM" Training Weight (lbs). Equations were calculated for sit up and arm curl only for incremental training weeks. Multiple regressions increased correlation coefficients for all four weight lifting motions.

	Rectilinear					Exponential			
Training Weeks	a[a]	b[a]	r(n)[b]	p[c]	Training Weeks	a	k[d]	r(n)[b]	p[c]
					Sit Up				
Week 1	28.9	6.62	.709(7)	NS	Week 1	87.4	.030	.784(7)	<.05
Weeks 1 & 4	-17.6	8.17	.749(14)	<.01	Weeks 1 & 4	72.4	.035	.799(14)	<.01
Weeks 1 & 8	187.7	1.91	.456(14)	NS	Weeks 1 & 8	187	.007	.454(14)	NS
Weeks 1 & 12	71.8	5.51	.733(14)	<.01	Weeks 1 & 12	137	.017	.753(14)	<.01
					Arm Curl				
Week 1	-63.5	4.93	.694(7)	NS	Week 1	58.0	.022	.762(7)	<.05
Weeks 1 & 4	-153.6	6.28	.711(14)	<.01	Weeks 1 & 4	38.5	.028	.775(14)	<.01
Weeks 1 & 8	-27.9	4.50	.625(14)	<.05	Weeks 1 & 8	74.4	.019	.682(14)	<.01
Weeks 1 & 12	-224.0	8.04	.663(14)	<.01	Weeks 1 & 12	45.2	.027	.775(14)	<.01
					Multiple Regressions (weeks 1 and 12)				
Sit up + Arm curl			.746(14)	<.01	Sit up + Arm curl			.810(14)	<.01
+ Bench press			.780(14)	<.01	+ Bench press			.862(14)	<.01
+ Leg press			.783(14)	<.01	+ Leg press			.863(14)	<.01

a: $G = a + bW$ where G = SACM tolerance in sec; a = intercept; b = slope (rate of change in SACM tolerance; W = training weight (80% of 1RM). b: r = correlation coefficient; n = number of pairs per determination. c: p = probability of chance occurrence (NS = not significant $P > 0.05$). d: $G = ae^{kW}$ where G = SACM tolerance in sec; a = intercept; k = slope (rate of change in SACM tolerance; W = training weight (80% of 1RM).

Table XII. Fatigue scores and SACM Tolerance times (group means ± S.E.) are shown for experimental weeks 1, 11, and 12. A high fatigue score indicates low fatigue.

Group	Fatigue Scores: Week 1 Pre	Week 1 Post 1[a]	Week 1 Post 2[a]	Week 11 Pre	Week 11 Post 1	Week 11 Post 2	Week 12 Pre	Week 12 Post 1	Week 12 Post 2	SACM Tolerance[b] (sec) Week 1	Week 11	Week 12
C	14.8	8.6	11.6	15.1	8.1	12.0	15.1	6.2	12.2	195	179	242
	±0.81	0.84	0.84	0.66	1.19	0.98	0.45	0.62	1.20	34	37	39
R	15.0	8.7	11.4	12.4	9.1	11.9	14.1	8.3	11.1	180	164	226
	1.00	1.64	0.95	1.29	1.08	1.30	1.55	1.34	1.32	31	20	33
W	16.7	8.0	12.1	15.7	12.3[c]	13.2	15.7	8.8	14.0	232	232	411
	1.17	1.50	[illegible].32	1.33	1.63	1.58	0.80	2.10	1.41	33	40	67

a: Post 1 is immediately after G exposure; Post 2 is 20 min after G exposure.

b: SACM exposure for week 11 was specified to be the same as for week 1. In some cases the members of groups C and R were unable to accomplish week 1 tolerance times. Tolerance times for weeks 1 and 12 are the same as shown in Table VIII and are shown here only for comparative purposes.

c: The Pre, Post 1 and Post 2 values for each group for weeks 1, 11, and 12 respectively were statistically analysed by analysis of variance. For group W Post 1 (immediately post G) the value of $F_{2/10} = 4.385$ was significant at $P < .05$. Further analyses by Paired T analysis indicated that week 11 fatigue scores were significantly higher ($P < .05$) than week 1 scores.

Table XIII. Blood lactate levels and changes in plasma volume associated with exposure to the SACM are shown as group means ± S.E. for weeks 1, 11, and 12. SACM exposure durations for each group are found in Table XII.

Blood Lactate (mg %)

Groups	Week 1			Week 11			Week 12		
	Pre G	Post 1[a]	Post 2[a]	Pre G	Post 1	Post 2	Pre G	Post 1	Post 2
C	5.6 ±1.51	32.9 2.86	18.1 1.37	6.3 1.52	24.3 2.85	14.0 2.7	10.4 1.45	37.3 3.99	20.8 1.81
R	3.9 1.55	36.4 5.94	22.3 2.66	5.8 0.98	29.7 6.12	20.1 2.64	6.9 0.67	42.0 5.66	25.6 3.16
W	4.8 1.02	21.4 3.14	13.5 2.73	10.6 2.05	31.4 3.19	15.9 2.06	11.2 2.38	32.3 5.43	22.5 4.20

% Plasma Volume Loss[b]

Groups	Week 1	Week 11	Week 12
C	18.8% ±3.53	16.9 2.84	17.5 2.76
R	15.1 1.90	14.4 2.47	16.4 2.48
W	13.2 2.80	13.4 1.37	18.6 4.05

a: Post 1 is immediately after G exposure; Post 2 is 20 min after G exposure.

b: % loss of plasma volume resulting from SACM exposure was calculated from hematocrit changes using methods referenced in the text.

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